SCIENTIFIC PROCEEDINGS

OF THE

Ohio Mechanics' Institute.

PUBLISHING COMMITTEE.

ROBT. B. WARDER, *Editor.*

LEWIS M. HOSEA.	JAS. B. STANWOOD.
ORMOND STONE.	H. T. EDDY.

VOL. I.

1882.

OHIO MECHANICS' INSTITUTE,
DEPARTMENT OF SCIENCE AND ARTS.
CINCINNATI, OHIO.

General

Rec'd 7-12-39 Lib 2-

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SCIENTIFIC PROCEEDINGS

OF THE

OHIO MECHANICS' INSTITUTE.

VOL. I. JANUARY, 1882. NO. 1.

EDITORIAL.

THE "diffusion of useful knowledge" being the prominent object in the foundation of the Ohio Mechanics' Institute, as declared in its constitution, the propriety, indeed the necessity, of maintaining a medium of official communication with kindred institutions, the press, and the public, will be conceded.

By the resolution establishing the Department of Science and Arts, the scientific duties of the Institution are confided to that body, which is, in effect, an enlarged Committee of the Institute membership, similar in general scope and relation to the parent stem, to the "Committee of Arts and Sciences" of the Franklin Institute of Philadelphia. By the same resolution, the Department of Science and Arts is charged with the publication of "such of its proceedings, including reports on inventions, papers and discussions of scientific interest as may be deemed valuable to the public," in the form of a quarterly journal in the name and on behalf of the Institute. These PROCEEDINGS are the fulfillment of the duty thus indicated.

While the scope of the present publication is limited, therefore, to matters originating with or brought before the Department of Science and Arts, including its various sections, the discussions at these meetings, as will elsewhere appear, have taken and are intended to take a wide range; and it is the controlling purpose in the organization of the Department and the conduct of its general meetings to deal with questions of the widest interest and greatest value coming within the domain of the physical and mathematical sciences and their practical applications. The subjects of Smoke Consumption, Inland Navigation, the Form and Size of the Earth, Food Adulteration, Steam Boiler Explosions, Comets, and others, which have already come before the Department at large and formed the staple

of interesting and instructive discussion, will illustrate the nature of its work and give an earnest of the interesting and useful character of the information which this publication may be expected to present to its readers, as well as contributions to science in the nature of original investigations presented to the Sections. Contributions may be expected from some of our members who are active in the pursuit of pure science, and from others who are qualified by experience and observation in the industrial pursuits to contribute valuable information on topics of practical interest. We may also expect papers from corresponding and honorary members residing elsewhere, who may thus express their sympathy with our objects and labors.

The Publishing Committee will endeavor to secure the issue of the SCIENTIFIC PROCEEDINGS at stated intervals; and while preference will always be given to actual contributions to science, it will be the aim not to give the papers too abstruse and exclusive a form, but to make them intelligible to as large a class of readers as possible, in accordance with the original purpose of the Institute.

SMOKE prevention has engaged the attention of philosophical minds in England and France ever since the exhibition of Delasme's "Base Burner," at St. Germain, in 1685; or, certainly, from the date of Watt's Smoke-Burning Furnace, patented in 1785.

The interest in the subject is of course dependent to a great extent upon local conditions—the prevalent use of bituminous coal and a generally moist and foggy atmosphere being the chief causes operating to keep the English people constantly on the alert to discover and enforce the means for the prevention of the nuisance. In the United States, however, the subject has generally received but little attention, owing to the indifference of manufacturers to the public convenience on the one hand, and the disinclination of municipal authority to deal with the matter, from various causes, on the other.

The city of Cincinnati, however, with its extensive and growing manufacturing interests, has been peculiarly a victim to the costly evils of a smoke-burdened atmosphere; the topographical situation of the city being such as to aggravate the evil beyond what is suffered by many other cities producing, perhaps, an equal amount of smoke. The site of the city being in a semicircular basin, with a cincture of high lands on all sides, through which the Ohio River cuts a narrrow channel in a course a little south of west, an eddy is formed in the currents of air flowing over the

face of the country from whatever direction. This is particularly true of the westerly breezes, which generally prevail, with reference to the high and almost unbroken escarpment of hills on the west. It is no unfamiliar sight to the suburban residents approaching the city in the early morning, particularly in the spring and early fall months, to gaze from the adjacent hill-tops over a lake of impenetrable smoke overhanging the city, filling the basin in which it is situated, from hill to hill, so dense as not only to obscure, but absolutely cut off the view even of the most ambitious church spires.

The action of the air currents can, at such times, be easily perceived as they pass above this pall of smoke without disturbing it; and the cloud hangs over the city, gradually raining its almost invisible, but costly shower of soot, destructive to cleanliness, health, property, good temper, and even to self-respect.

The serious nature of this evil, in view of the appalling prospect of its continued increase, naturally drew attention to itself as one of those questions in which the Department of Science and Arts might render an important public service, and the subject, in various forms, has been under consideration before the Department.

One of the stated papers on this subject, delivered before the Department by Mr. Nelson W. Perry, Instructor in Metallurgy at the University of Cincinnati, is published in full in this issue, and will be found to present a clear view of the fundamental principles on which rational combustion depends. Another exceedingly interesting and valuable contribution to the literature of the subject was read by Mr. H. M. Lane, M. E., at the meeting of June 7, 1881, and will probably appear in the next number of these PROCEEDINGS.

These discussions, it may be fairly claimed, were instrumental in securing the final passage of the "Smoke Ordinance," which became a municipal statute of Cincinnati on the first of January, 1882—albeit the credit of having originated the public movement that finally took shape in the ordinance referred to, must be conceded to the Ladies' Association, which labored faithfully to this end from the beginning.

The ordinance is substantially like the English municipal acts that have been in force for many years. It declares the emission of smoke from furnace chimneys to be unlawful, and punishable by the fine or imprisonment of the superintendent or person in charge; and appoints an inspector charged with the duty of giving notice to derelict offenders and enforcing the provisions of the statute by proper legal proceedings. As the ordinance, at this writing, has not yet taken practical effect, it is too early

to speak of its merits or the effectiveness of its operation; but it is obvious to the most limited discernment that there can be no retrogression and that the evil must be grappled with and fought to the death.

The main objection urged by manufacturers affected by the ordinance is, that smoke prevention, as an industrial problem, is not practicable; and even some mechanical engineers, who should know better, persist in declaring that the best evaporative results in the use of steam boilers are inconsistent with a perfect fuel combustion. Such assertions are not creditable to the intelligence either of manufacturer or engineer. There can not be a more elementary or obvious deduction from known facts, than that economy and efficiency in the use of fuel are attained in precisely the degree in which perfect combustion is approximated; and because, with existing structures, crude and unphilosophical as most of them are, a perfect combustion can not be approximated without sacrificing evaporative efficiency, (if such be the fact,) this furnishes no reason to question the truth of the general proposition. It proves nothing, indeed, but that to attain the best results requires improved structures built with some regard to correct scientific principles, and operated with the intelligence and care requisite to maintain proper conditions. In so important a matter as the firing of steam boiler furnaces, where the evils of ignorant and inefficient care fall so heavily upon the community, ignorance and inefficiency should not be tolerated as an excuse for a violation of the rule: *Sic utere tuo ut non alienum lædas.*

THE Department has lost one of its number by death during the past year. Mr. George Graham was one of the original members. He was connected with many public institutions; his long life was marked by an untiring interest in whatever concerned the public welfare of his adopted city; and except for his death which occurred March 1st, 1881, his sound judgment and his devotion to the spirit of progress would have been appreciated in our work. He was one of the founders of the Ohio Mechanics' Institute, and took a deep interest in all educational movements.

THE excursions of last year were pleasant, social, and instructive occasions. Let the number be multiplied for 1882, with an increased attendance of ladies.

PROCEEDINGS OF THE DEPARTMENT OF SCIENCE AND ARTS.

THE Department, which is entrusted with the scientific duties of the Ohio Mechanics' Institute, was organized January 5, 1881. Forty-six members were then enrolled. On January 26, By-Laws were adopted, and the following officers were chosen for the year: Chairman, Lewis M. Hosea; Corresponding Secretary, Nelson W. Perry, E. M.; Recording Secretary, John B. Heich.

A Committee was appointed to invite the members of the Cincinnati Chemical Society to become members of the Department, and to take part in establishing a Section of Chemistry.

Meeting of February 10.

On February 10, the first regular meeting was called to order by the Chairman, whose INAUGURAL ADDRESS set forth the special objects of the organization—to bring the scientist and the artisan into closer relations, and to promote a community of feeling between thinkers and workers. He also referred to the need of an industrial school, where young men and women may be trained in the intelligent and practical application of the principles of science to the industrial arts.

Prof. R. B. Warder offered a suggestion for the more efficient SURFACE DRAINAGE OF THE STREETS in winter.

Mr. Nelson W. Perry then presented a paper on "ECONOMY OF FUEL," which elicited some discussion; and a committee was appointed to investigate the subject of the smoke nuisance.

Meeting of March 10.

Prof. F. W. Clarke reported that the invitation extended to the Chemical Society had been duly accepted, and that the members had organized the Section of Chemistry.*

Col. P. P. Lane reported the organization of the Section of Mechanics and Engineering.

Col. Wm. E. Merrill then delivered a lecture upon "INLAND NAVIGATION AND HYDRAULIC CONSTRUCTION." The various forms of movable dams used in France, and those now constructed at Davis Island, in the Ohio, were illustrated with photographs, diagrams and models.†

*This name was changed November 29 to "Section of Chemistry and Physics."

†Reference may be made to Col. Merrill's official reports, including numerous translations from the French on movable dams, in the "Annual Reports of the Chief of Engineers to the Secretary of War," as follows:

Meeting of April 14.

Information was received by the Department that the members of the "Electrical Society of the Ohio Valley" had reorganized as a Section of Electricity. Their valuable collection of books (amounting to forty-three volumes) had been deposited in the library of the Ohio Mechanics' Institute.

The Chairman called attention to the expert tests of steam engines, which were to be conducted under the auspices of the Cincinnati Industrial Exposition, and invited members of the Department to enroll themselves as volunteer assistants for these tests.*

A committee was appointed to consider some appropriate mode of contributing to the entertainment of the American Association for the Advancement of Science, in August.

Mr. Alfred R. Payne read a paper on "STEAM BOILER EXPLOSIONS." The causes of a number of disasters were ably discussed, with the aid of diagrams.

Prof. F. W. Clarke made some remarks on the ADULTERATION OF FOODS, and especially on Mr. Angell's Congressional Report on this subject.

Meeting of May 12.

The Committee appointed at the last meeting in behalf of the American Association made a report, which was unanimously adopted; and

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Report for 1873, pages 540–542.
Report for 1874, part I., pages 406–410 and 415–481.
Report for 1875, part I., pages 686–735 and part II., pages 608–631.
Report for 1876, part II., pages 11–54.
Report for 1877, pages 635-661.
Report for 1878, pages 802–805.
Report for 1879, pages 1299 and 1308–1343.
Report for 1880, pages 1737, 1738, and 1753–1762.

The plates illustrating the reports of 1874 are found in the special "Report of the Board of Engineers on Hydraulic Gates and Dams" printed as Ex. Doc. No. 78, H. of R., 43rd Cong., 2d. Sess.

"Improvement of Non-Tidal Rivers," published at Washington in 1881, contains Col. Merrill's translations of recent memoirs by S. Janicki, Director of the Moskva Navigation Company of Russia, and by the French engineers, MM. Jacquet and Pasqueau of the *Ponts et Chaussées*.

Those who may be interested in this department of engineering are kindly invited by Col. Merrill to consult De Lagrené's "Cours de Navigation Intérieure," vol. 3; Malézieux's plates and various monographs in his office.

*A report of these tests will be embodied in the "Report of the Board of Commissioners of the Cincinnati Industrial Exposition" for 1881.

the Chairman appointed Messrs. Clarke, Dudley, Kebler, Stone, and Stanwood, to carry out the plans as suggested. The report is as follows:

CINCINNATI, May 12, 1881.

L. M. HOSEA, ESQ., CHAIRMAN OF DEPARTMENT:—We, the undersigned, appointed as a Committee to consider and suggest a form of entertainment to be given by the Department to the American Association for the Advancement of Science, herewith beg leave to submit the following report, viz:

It was our desire to decide upon some movement that would bring the Institute before the scientists throughout the country, and we would suggest that the Department appoint a Committee for the purpose of establishing a Loan Exhibition of Scientific Apparatus, Chemicals, Minerals, etc., to be held in the Exposition buildings during the session of the Association, and that the collection be held over to the regular Industrial Exposition.

It is suggested that the Committee act in conjunction with that of the Exposition, since the latter are taking steps in this direction by offering a complete list of prizes for this class of articles. It will, therefore, be the duty of the Committee to request dealers to loan their goods a few weeks earlier than would otherwise be necessary. A printed circular distributed with the Exposition premium list would accomplish this.

Since it has been the custom of a few dealers in the country to make small exhibits during the meetings of the Association, and since the Exposition Commissioners are making especial efforts in this regard, we desire to avail ourselves of this rare opportunity to present to the members of the Association such a display as has never before been seen in this country, and suggest it as a worthy charge for this Department.

Owing to the nearness of the approaching meeting, we further suggest that action on this matter be taken at once. Respectfully submitted,

WM. L. DUDLEY,
E. A. KEBLER,
ORMOND STONE,
JAS. B. STANWOOD, } Committee.

Prof. W. L. Dudley then presented a paper on "IRIDIUM," in which he explained the method by which its fusion is now accomplished with the aid of phosphorus.

Meeting of June 7.

Mr. H. M. Lane read a paper on "SMOKE PREVENTION;" various devices in use in London were illustrated and described.

The Department adjourned, to meet October 13.

Meeting of October 13.

Prof. F. W. Clarke, as Chairman of the Committee on the Loan Exhibition of Scientific Apparatus, reported that the effort was successful. The display was very satisfactory; and a large part of this Exhibition was continued through the Industrial Exposition.

Mr. L. M. Hosea presented a paper on the "CONSUMPTION OF

PULVERIZED FUEL AND SLACK." The subject was illustrated by diagrams of numerous forms of furnaces, and general discussion was elicited.

The Chairman reported that the Board of Directors would give their co-operation in providing for a course of public lectures.

Meeting of November 10.

The Chairman read a communication from Mr. T. P. Baldwin, inviting the Department to be present at the examination of Hutchinson's smoke consuming device by the jury of the Industrial Exposition this evening; also, an invitation from L. H. Weisleder, Superintendent of the Brush Electric Light Company, to visit their lighting station and the Butman smoke consuming device. Both invitations were thankfully accepted.

Mr. McMeekin submitted a series of questions relating to Natural Philosophy and its practical applications, for discussion at a future meeting. He also suggested that other questions be laid on the table, to occupy the attention of the Department in the absence of stated topics.

The Department then adjourned (at 8 o'clock), to visit the Brush Electric Light Station and the smoke preventing devices.

Meeting of December 8.

The Chairman submitted an invitation from the Hemingray Glass Company, for the Department to visit their works, in Covington, Ky., on the 12th inst. This invitation was thankfully accepted.

An application was submitted from George Cumming, of New York, requesting the Department to pass upon the merits of the "Cumming Periphery Contact" for telegraph keys. This application was referred to the Section of Chemistry and Physics for preliminary examination.

Mr. L. M. Hosea read a paper on the "LOCOMOTIVE TRIAL AT RAINHILL," giving an historical sketch of early efforts in steam locomotion, and the final triumph over popular predjudice.

Committees were announced as follows:

On Lectures—Messrs. Clarke, Stanwood, Dudley, McMeekin, and Stuntz.

On Publishing—Messrs. Warder, Eddy, Stone, and Hosea.

PROCEEDINGS OF THE SECTION OF MECHANICS AND ENGINEERING.

Preliminary meetings were held on February 12 and 24, 1881, when By-Laws were adopted, and the following officers were elected: Chairman,

Prof. H. T. Eddy; Vice-Chairman, Col. P. P. Lane; Recording Secretary, James B. Stanwood; Corresponding Secretary, Robert Laidlaw.

Meeting of March 17.

Prof. H. T. Eddy was appointed a member of the Publishing Committee.

Messrs. Stanwood and Baldwin read a paper on the "SHAPES GIVEN TO TEETH OF COG WHEELS." The three systems introduced by Willis, Robinson, and Walker, respectively, were illustrated by models, and the peculiarities and advantages of each noted. It was suggested that for gear cutting engines, a former or template might be made on the principle of Robinson's Odontograph, which would be sufficient for all practical cases.

Mr. McMeekin discussed the "COMPARATIVE VALUE OF FUELS."

Meeting of April 21.

A Committee to have charge of the programme for the regular meetings of the Section was announced by the Chairman.

Mr. Chas. B. McMeekin was appointed to represent the Section in the Lecture Committee.

Prof. Eddy read a paper upon "THE EARTH—ITS FORM AND SHAPE." Prof. Eddy explained how the earth's form resembles an orange, and the true form to which it approximates is defined as that which the earth would have were its surface all water. He explained how the true level varies in places, due to local attraction of large masses of matter, either upon the surface or of greater density beneath. As an example, if a canal could be excavated through a mountain range, so that the sea water could enter it, the water level would be higher at the center of the range than at the sea, due to this attraction of the mass of earth forming the mountains.

The next paper was by Mr. Daniel Ashworth, upon the "MANUFACTURE OF GLASS." This paper was illustrated by diagrams showing the construction of the furnace and pots used in melting the glass; also, the method of generating gas for fuel, and the means of conducting it to the furnaces. Mr. Ashworth exhibited a number of specimens of glass made at the Hemingray Glass Works in Covington, Ky.

Meeting of May 19.

A paper on "WOOD WORKING MACHINERY" was read by Mr. Geo. W. Bugbee, who first gave an historical sketch of the development of this class of machinery, and described the leading tools —the circular and

band saws and the planing machine—and then showed in what direction further development tended, and gave the speeds at which certain cutters are run. He stated that revolving cutters, such as are used on planing machines, could be run much faster when short than when long—due principally to the greater tendency to spring when the mandrels were long.

Meeting of October 20.

At the first regular meeting after the summer interval, a description was given of the WILSON GAS GENERATOR by Mr. Rickey, of New Orleans. This furnace has been used in England extensively for generating gas that can be used as a fuel, either under boilers or in furnaces of any kind. The principle involved was the generation of gas from coal or slack at a low rate of combustion, the gas being conveyed directly to the furnace.

Meeting of November 17.

As the result of the disastrous EXPLOSION at Dayton, Ohio, OF A NEW TUBULAR BOILER, Mr. Alfred R. Payne prepared a description of the boiler as seen by him after the accident. The boiler was one of two in a battery, and was very poorly supported upon the foundations. The boiler had a steam dome united by two legs to the shell. This construction was severely criticised as tending to cause grooving in the bottom sheets, the top being firmly braced by the drum. The boiler seemed to have first ruptured at the bottom sheet beneath this dome.

Meeting of December 15.

The interest in boilers, their furnaces, and the manner of constructing them, led Mr. J. G. Danks to explain the construction of the DANKS MECHANICAL STOKER, as used at the Cincinnati Rolling Mill. The fuel is fed into a short furnace built immediately in front of the boiler; the bridge-wall is directly under the front head of the shell. With this furnace a forced draught is employed, it being delivered beneath the grate and at the bridge-wall. The fire-bed is quite deep, and the coal is fed into it by screws or augers operated by machinery.* The delivery of fuel through these augers is regulated by varying their speed. This furnace has given good results as a smoke preventer. Following this paper was an animated discussion upon boilers and their settings.

* A similar screw-feed, for furnaces, is described (with illustrations) in the *Scientific American Supplement*, January 18, 1879, page 2523.

PROCEEDINGS OF THE SECTION OF CHEMISTRY AND PHYSICS.

Meeting of March 3, 1881.

In accordance with an invitation of the Department of Science and Arts, a meeting of the Cincinnati Chemical Society was held in the rooms of the Institute, and the following resolution was adopted:

Resolved, That the Cincinnati Chemical Society adjourn *sine die*, and that we, the members, form a Section of Chemistry of the Department of Science and Arts of the Ohio Mechanics' Institute, with the same objects as those of the above-named Society.

Officers were chosen as follows: Chairman, Prof. F. W. Clarke; Vice-Chairman, Dr. F. A. Roeder; Recording Secretary, Prof. Wm. L. Dudley; Corresponding Secretary, Dr. Alfred Springer.

Robert B. Warder was appointed to represent the Section in the Publishing Committee, and C. R. Stuntz for the Lecture Committee.

Mr. John L. Irwin read a paper on the "PROXIMATE ANALYSIS OF PLANTS AND CRUDE DRUGS."

Prof. Clarke and Prof. Lloyd volunteered to read papers at the next two meetings.

Meeting of March 24.

Mr. L. M. Hosea spoke of a Congressional bill, designed to prevent adulteration of foods, and recommended some investigation of possible frauds.

Prof. Warder read a paper on "ALKALIMETRY WITH PHENOL PHTHALEIN AS INDICATOR." This was illustrated by the use of burettes and reagents.

Prof. Clarke reported some LABORATORY NOTES of work done under his direction in the chemical laboratory of the University of Cincinnati. Abstracts will be found below.

Meeting of April 21.

Prof. Warder gave a review of BRODIE'S "IDEAL CHEMISTRY."

Dr. A. Springer suggested that lectures be delivered at each meeting of the Section on subjects of importance which do not receive the attention they deserve in this country. He also volunteered to open such a course with two or more lectures on Fermentation, as follows:

1. History of Fermentation, and complete study of the Saccharomyces; their physiological and biological functions.
2. Assimilation of food of the Saccharomyces.
3. Butyric and Lactic Fermentation and Putrefaction.

Meeting of May 26.

Dr. Springer read his first lecture on FERMENTATION.

The Section then adjourned for the summer vacation.

Meeting of October 27.

Prof. Warder proposed a change of name from "Section of Chemistry" to "Section of Chemistry and Physics."

Dr. Springer read a second lecture on FERMENTATION, which elicited considerable discussion.

Meeting of November 29.

The Constitution was amended (as proposed at the October meeting), changing the name to "Section of Chemistry and Physics."

Prof. Warder reported a partial examination of the antiseptic gas (sulphur dioxide) used by the "Prentiss Preserving Company," under the name of "OZONE."

Prof. Clarke gave a brief outline of his recalculation of the atomic weights, [See Abstract in *Amer. Chem. Journal*, **3**, 263, and *Philos. Magazine* (5), **12**, 101], and discussed PROUT'S HYPOTHESIS. Prof. Clarke showed that out of sixty-six elements, forty have values falling within a tenth of a unit of whole numbers. Among the remaining twenty-six, some have been so badly determined as to carry but little weight; while the majority of them are subject to corrections, which, if applied, would bring their atomic weights within the limit of a tenth of a unit variation. Hence, the author concludes that it is more probable that the seeming exceptions to Prout's law are due to undiscovered constant errors, than that the many agreements with it should be mere coincidences.

Mr. N. W. Perry exhibited a NEW MINERAL from the neighborhood of Gunnison City, Colorado, the analysis of which is still in progress. It is of a deep violet blue color, about 3½ in the scale of hardness, gives purple streak, is phosphorescent when heated, and, as far as yet determined, is a silico fluoride of lime and alumina. What adds especial interest to it, however, is the presence of a base as yet not recognized. This base has many properties in common with the metals of yttrium and cerium groups, to which it probably belongs; but as to which of these metals it is, or whether it is a new one, he has not yet been able to decide.

Meeting of December 22.

A communication relating to the "Cumming Periphery Contact" for telegraph keys, etc., had been referred by the Department to this Section. This invention was considered worthy of fuller examination, and it was

accordingly referred back to the Department, with the recommendation that an Examining Board be appointed, as provided in the By-Laws.

Prof. Warder gave some further results of his examination of prepared sulphur, sold as "OZONE."

Dr. Springer thought that the antiseptic property of sulphur dioxide would be more transient than that which is claimed for the new preparation; and that, perhaps, thymol, chinoline, resorcin or cinnamic acid may be added.

Dr. Springer then read an abstract of WALD'S THEORY OF ENERGY-PRODUCING CHEMICAL ACTION. [See *Monatshefte f. Chemie etc.*, **2**, 171; or abstract in *Wiedemann's Beiblætter*, **5**, 735.] Wald regards the heat developed as an *obstacle* to a chemical reaction whenever the resulting molecule would be heated beyond its temperature of dissociation; hence the possibility of a given reaction often seems to depend upon the number of "refrigerating molecules" present, by which a part of the energy is abstracted, and the resulting temperature is moderated.

Prof. Warder read a paper on "THE STICKING OF THE TELEGRAPH KEY."

I.—ECONOMY OF FUEL.

By NELSON W. PERRY, E. M.

[Read before the Department of Science and Arts, Feb. 10, 1881.]

I have been requested to read a paper before you on "Consumption of Smoke." I have preferred to make the title of my paper a little more general—including not only a discussion of the methods, or, rather, the conditions under which smoke, when formed, may be consumed, but also the conditions, the observance of which will *prevent* its formation; and suggestions as to methods of utilizing, as fuel, that large class of carbonaceous material which is now not only of no commercial value, and unutilized as fuel, but is in many cases a waste product, and a source of expense. I refer in the latter clause to coals containing too much ash or mineral matter, sulphur, etc., to be used by our present methods, coal dust or slack, tanbark, sawdust, etc.

In sections of country where the fuel is largely bituminous coal, and especially in commercial and manufacturing centers as Cincinnati, Pittsburg, etc., the waste of fuel in the form of unconsumed combustible gases and smoke becomes of serious moment. Attention is attracted to it not on account of the money or fuel lost up the chimney, but on

account of the nuisance created in the form of soot, or finely divided carbon, after it gets out of the chimney—defiling the air we breathe, and everything that is capable of taking up dirt. Since the introduction of steam as a motive power has this been regarded as a nuisance, and inventors have suggested devices for its obviation. The plans adopted have been good, bad, and indifferent; and, also, not a few, absurd. The number of patents issued for appliances to consume or prevent smoke under steam boilers, in England and in this country, runs up into the thousands, with many essential repetitions down to the present day. To describe them all would be impossible; to mention a few would be to lay one's self open to the charge of malice or favoritism. I do not therefore purpose to discuss patents, but principles; but I hope to be able to point out the directions in which success may be looked for, and to guard against those in which failure is inevitable.

For a proper understanding of the subject, we must first turn our attention to the elements involved—*air*, including oxygen and nitrogen; our fuel, whatever that may be, and our appliances for utilizing these elements to the best advantage. The composition of air has been determined in pretty much all parts of the world, and found very constant. It usually contains about twenty-one parts by volume of oxygen and seventy-nine parts by volume of nitrogen. The term fuel, in a commercial sense, is confined to the various kinds of coal, including charcoal, bituminous and anthracite coal, wood, and peat, and their products of distillation, including gas and petroleum. Our subject brings us to discuss only the bituminous coals, with their variations, as such are our fuels and are our smoke producers.

The term combustion, as it interests us, is the rapid oxidation of our fuel with evolution of heat.

The elementary constituents of our fuel are carbon and hydrogen; the impurities or useless ingredients, ash, including incombustible and other deleterious mineral matters, water, nitrogen, etc. Now, although we can, as chemists, determine just how much hydrogen, just how much carbon, just how much oxygen, and just how much ash or mineral matter there may be in our fuel; and although we know, both theoretically and practically, under just what conditions the carbon and hydrogen can be ignited to the best advantage, we have other problems to deal with than those suggested by the above-named elements. It is not simply hydrogen and carbon that we have to burn, and it is not simply oxygen that we have to burn them with. We know, however, just what weight of oxygen is required to burn a given weight of carbon or hydrogen

under the most favorable circumstances; and, if we know the exact state of hydration of the atmosphere, and its exact chemical constituents at the time of experiment, and the barometric pressure, we can calculate the exact volume of air required to completely burn our fuel, composed of carbon and hydrogen, under conditions most favorable to combustion. But the problem is not so simple outside of the laboratory. We have in commercial practice not simply carbon and hydrogen to deal with as fuels; not simply oxygen as the gas we furnish to our fuel to burn it; but a complexity of compounds of carbon and hydrogen as fuel, very imperfect conditions for the utilization of their heat when consumed; and, as diluants of our oxygen, we have the products of complete combustion of carbon—carbonic acid gas (which is used in the patent fire extinguishers to stop combustion); of hydrogen, water, which absorbs large amounts of heat in its gasification; and last, but not least, the nitrogen of the air that we have to admit along with the oxygen. Nitrogen, like carbonic acid gas, is a non-supporter of combustion; and its influence is realized when we understand that when we introduce to the furnace one cu. foot of atmospheric oxygen, we are also introducing four cu. feet of a substance that is not only a non-supporter of combustion, but which also must be heated at the expense of our fuel, viz: nitrogen. Then, too, a large amount of heat—to say nothing of combustible gases and solids—passes up our chimneys; all of these are necessarily losses in effectual heating power of our fuel. If bituminous coal be thrown upon a hot fire, the process of destructive distillation will ensue. The portions of coal in contact with the hot fire will lose a certain class of distillates; those a little removed will part with volatile products, which result from a less intense application of heat; and those furthest removed from the fire, or on top, have yet to be warmed before distillation takes place, and act as coolers to the distilled products coming up from below. Let us glance at the products of distillation that may arise when coal is subjected to varying heat. There arise gases, both simple and of the utmost complexity; gases that readily combine with oxygen, and those that will either not combine with oxygen at all, or will do so only under the most favorable conditions. There are also two phenomena observed. The one, that gases or vapors, if cooled below a certain temperature, condense to the liquid state; the other, that some gases, if brought into contact with incandescent coal, are split up into simpler compounds with the deposition of finely divided carbon.

Combustion, as before stated, in a commercial sense, means the rapid oxidation of our fuel with evolution of heat. For the purpose of burning

our bituminous fuel, this same heat gives rise to many more or less combustible gases, as products of distillation from those portions not yet in a state of combustion, or imperfectly so. These gases, so different from each other in their constitution, are so largely diluted with non-supporters of combustion, viz: nitrogen from the air and carbonic acid gas (the result of complete combustion of carbon), that they easily make their escape through the chimney without combustion, thus, not only causing a loss of the heat they themselves have absorbed in taking the gaseous form, but also what they are capable of producing by their combustion.

It is clear, I take it, that if a combustible gas be largely diluted with other gases inimical to combustion, its combustibility will be very largely reduced, and can be accomplished only under the most favorable circumstances; and, if this dilution be carried far enough, this gas becomes commercially incombustible.

Let us discuss, briefly, the phenomena that occur in the ordinary furnace, as used for generating steam. There are two columns—the descending and the ascending column. The descending column is the fuel—cold and undecomposed at the beginning or when it is charged, and resulting at its lower end in ash and clinker. The ascending column begins at the grate bars as cold air, and passes up the chimney in a condition modified according as it has done its work more or less effectually. There is another factor in this discussion that we may designate as the *horizontal* column, which consists of all air admitted to the furnace not passing through the grate bars and bed of ignited fuel.

The Ascending Column.

The atmospheric air passes through the grate bars, comes in contact with incandescent carbon (with which it unites to form carbonic acid gas—this is complete combustion), and generates the greatest heat possible by the union of oxygen and carbon. The carbonic acid thus formed—a non-supporter of combustion—passes on upward and comes into contact with other incandescent fuel and takes therefrom an additional atom of carbon, becoming carbonic oxide gas instead of carbonic acid gas, absorbing a certain amount of heat, and becoming by the change a combustible gas, which, on burning, becomes again carbonic acid. This change may repeat itself many times—the conditions most favorable to its repetition being a thick bed of incandescent fuel. As the zone of incandescence is passed, the carbonic acid gas that has not been reconverted into carbonic oxide, passes its last chance of becoming a combustible substance, and proceeds on its way to the stack or chimney, an

enemy to further combustion and a disadvantageous diluant to both our ascending and horizontal columns. The carbonic oxide which may have escaped combustion thus far, together with that generated from the fuel above by incomplete combustion of the coal, passes up under the boiler to be burned by the horizontal column, or to pass up the chimney unconsumed. The nitrogen, which is necessarily introduced along with the oxygen, passes up unchanged, absorbing heat, requiring an expenditure of and consuming fuel in that respect as truly as does the water in our boilers; this heat is not all lost, however. The heated gases, combustible and incombustible, passing through the fuel, transfer a portion of their heat to particles of less temperature than themselves, giving rise to the various products of distillation before referred to, and are still further cooled by the heat which always becomes latent when solids become liquids, or liquids become gases. The ascending column, therefore, emerges from the top of the bed of fuel cooled, and especially after a heavy charge of new fuel, very much cooled, consisting of a large amount of nitrogen, and varying amounts of vapors, carbonic acid, and combustible gases.

The Descending Column.

Fresh coal is thrown on the grate. It becomes gradually heated by the hot gases from below, and loses its hygroscopic and combined water by volatilization. The water, on passing into the state of vapor, absorbs practically as much heat as the same amount of water in the boiler would require to convert it into steam. Worse than this, the absorption of heat tends to cool both the ascending column, which is to heat our boiler, and the coal from which it was generated, rendering that particular piece of fuel less fit for combustion than it otherwise would be. This piece of coal gradually descends, approaching nearer the seat of combustion, and becoming hotter and hotter. Distillation proceeds. At first, condensible vapors are driven off; and, as the heat increases, more permanent gases are evolved—each in its turn rendering latent a certain amount of heat, and impairing the progress of the piece of fuel towards that condition wherein complete combustion is possible. Finally all the volatile matters are driven off, and only pure carbon and ash remain. Our piece of coal has now arrived at a point where the cooling effect of distillation is no longer experienced, and it unites with the oxygen of the air to form carbonic acid, and with carbonic acid to form carbonic oxide, until all the carbon is gone and nothing but the ash is left. This ash, if maintained long at high temperatures, tends to fuse and form clinker. It largely takes care of itself, however, and falls through the grate bars.

If, however, these should become clogged, so as to expose the ash to great heat for a sufficient length of time, it would form clinker which would beget other clinker, impairing the draft and rendering complete combustion less possible.

The Horizontal Column.

When the ascending column has emerged above the bed of fuel, it has become devoid of free oxygen, or, at least, nearly so. It therefore becomes necessary to admit a fresh supply to consume the combustible gases which otherwise would be lost up the chimney. This fresh supply of air is what I have termed the horizontal column, and is usually admitted through the fire-doors. A very large excess of air over that theoretically required must be admitted, on account of its imperfect mixing with the combustible gases. This excess of air, and its imperfect mixing, are the most fertile causes of smoke and waste of fuel, as we shall see. Inventors, realizing this fact, have attempted to correct the fault, either by dividing up their horizontal column into several—admitting the air not alone through the fire-doors, but at several points—or by causing the air and gases to describe circuitous paths, thus causing a better mingling. A simple and favorite way of accomplishing this is by hanging a curtain or curtains in the combustion chamber from the crown to within a few inches of the fuel-bed. Upon these two principles and combinations of these two with others, are founded almost all of the more successful devices for economy of fuel or consumption of smoke.

It is a well-established fact that all substances must be first heated to a certain temperature before they are capable of combustion. If we keep our air and our gases at a temperature below this, they can not ignite. Again, if we have a flame, and cool it sufficiently, it is extinguished. If the flame be one from the combustion of a rich hydrocarbon gas, such as is produced very largely from bituminous coals—a luminous flame—if this be cooled, it will deposit a finely divided carbon. This same result follows if such a gas be burned in a deficient supply of air, or if such a gas, unconsumed, comes suddenly in contact with incandescent fuel.

These facts, and the phenomena just described, are very prettily illustrated by the flame of a candle and the Bunsen burner.

I have here a Bunsen burner, such as is used in the laboratory for generating heat for chemical work. It differs from the ordinary gas burner in that atmospheric air is thoroughly mixed with the gas before it is ignited. You see that under these circumstances the gas

burns with a non-luminous flame. The combustion is not only complete, but rapid and intense; there is no waste and no smoke. Intense and perfect as this combustion is, I can so reduce the temperature of the gases (air and illuminating gas) as to render their union or combustion impossible. I have here a piece of ordinary wire gauze. This is cold, and the wires will rapidly dissipate the heat if I place them in the flame, thus cooling it below the temperature necessary to its existence. By applying heat above the gauze, however, I can bring the gases back to the required temperature and they will again burn, their combustion generating the required heat to keep them in this state. If, however, I first heat my gauze, so that its interposition no longer cools the gases below their temperature of combustion, the flame will continue as before, notwithstanding such interposition. Thus far, we have mixed our air and combustible gas *before* imparting to them the temperature necessary to combustion. By a simple contrivance, I prevent the previous mixture of air with the gas, and we have now a highly luminous flame – the combustion is still essentially complete; there is little or no smoke, but the heat generated is far less than in the former case—the combustion is less intense. The unignited gas, containing carburetted hydrogen, comes into contact with an envelope of gases in a state of combustion at high temperature and is decomposed with separation of finely divided carbon, which, in its turn, is heated to a high state of incandescence and gives us the light. If the supply of air is sufficient, these particles of incandescent carbon are completely burned before they pass beyond the limits of the flame, and no smoke is formed. If, however, the supply of oxygen be deficient, or the flame be suddenly cooled below the temperature at which combustion can take place, these particles of carbon will escape unconsumed, forming smoke. Let us take the combustion of a candle as an example. We bring the wick to the required temperature, by bringing it into contact with a lighted match. It burns, and the heat of this combustion first melts and then distills the carbonaceous matter surrounding it, forming rich hydrocarbon gases. These rise, and, when they come into contact with sufficient oxygen, unite with it and form a flame. You have all observed, however, that there is a cone within the flame that is gaseous and not in a state of combustion; this cone is composed of the rich hydrocarbon gases, the products of distillation of the surroundings of the wick. It needs only the requisite temperature and sufficient oxygen to bring them to a state of combustion, which they soon acquire as they ascend. Before they receive their oxygen, however, they become so highly heated as to be decomposed, with separation of finely divided carbon; this becomes

luminous from the high temperature to which it is exposed, and, finally, when it reaches the oxygen of the air, is consumed, forming a non-luminous envelope to the whole flame, like the Bunsen flame, forming again an example of complete combustion, and, consequently, a hot and smokeless flame. If this inner, non-luminous cone be unconsumed gases, as we have stated, we can draw them off, and, on supplying the proper conditions, burn them at a distance. This I will do by introducing into this cone one end of a glass tube; applying a match to the other end, we obtain a flame which is the gas from the inner cone in a state of combustion. I have said that the candle flame is an example of complete combustion. If, however, this flame be surrounded by an atmosphere deficient in oxygen, it ceases to be such, and the particles of incandescent carbon escape unburnt, and we have smoke. Also, if we interpose some cold body, such as porcelain or glass, these same particles are cooled below their temperature of combustion, and escape as soot. A study of these phenomena gives us an insight into the causes of smoke and incomplete combustion in our furnaces, and, consequently, indicates means for their prevention. The analogy is very close. When a fresh charge of fuel is introduced into the furnace, it is cold, and acts as did the wire gauze in the Bunsen flame—cools down the flame which was the result of complete combustion, and, consequently, the very hottest—allowing combustible gases to come into contact with the horizontal column as yet unconsumed; also, cooling the luminous flame to a point where the minute particles of incandescent carbon can no longer burn, and they come in contact with the horizontal column as smoke.

Our horizontal column, being a current of cold air, still further cools these products which it was intended to burn, removing them still further from the conditions favorable to their combustion. Our horizontal column, too, is the strongest, and, consequently, the most cooling, at the time when it should be least so, viz: when fresh fuel is charged—the door being kept wide open during that operation. One essential for the prevention or consumption of smoke is, therefore, that our horizontal column should always be under control; and large variations, especially at time of charging fresh fuel, should be avoided. This may be accomplished by the application of mechanical stokers, which do away with the necessity of opening the furnace doors.

Our fresh charge of fuel finally becomes sufficiently heated so as not to cool our gases below their point of combustion, as did our wire gauze, and they are then in a favorable condition to be burned. The time elapsing before this state of affairs is brought about depends largely upon

the size of the particles of fuel charged, and the depth or thickness of the charge, a thin layer of fuel becoming more quickly heated than a thick one. It is economical of fuel, therefore, to charge the fuel often and in small quantities, rather than more seldom and in large quantities. This involves increased labor on the part of the stoker, which it is difficult to obtain without interested supervision, and would involve more frequent opening of the doors. Here, again, would a good mechanical stoker recommend itself.

Size of Fuel Charged.

Within limits, the smaller the pieces of fuel charged, the sooner the layer will become heated, and the sooner their cooling effect will vanish, since the time required to heat a large body is much greater than that required to heat the same amount of matter in a number of smaller bodies. There is a limit, however, in practice. The pieces must not be so small as to impede the ascending column. The interstices between the pieces of fuel must be large enough to permit an easy passage of the air and the products of combustion from below, else incomplete combustion will follow and waste of fuel ensue. It therefore follows that the two extremes of too large and too fine fuel should be avoided. The fuel may be the finer, the thinner the layer charged. As a perfected mechanical stoker will enable us to make more frequent and, consequently, thinner charges, so it will enable us to utilize as fuel, with little or no smoke, coal dust and slack; which, if used under other circumstances, would belch into the atmosphere volumes of black smoke and furnish but little heat.

We have seen that our horizontal column, though it is a necessary evil as our furnaces are at present constructed, is a very fertile cause of waste of fuel, due to its cooling effect upon the combustible and other gases of the ascending column. Why not heat our air before admitting it to the furnace? It is answered that to build a supplementary furnace for this purpose would be out of the question, and of very doubtful expediency. We can not utilize that vast amount of heat passing up our chimney to heat our air, since to do so, would be to impair our draft, and, consequently, to diminish the intensity and completeness of our combustion. Very true; but why not do away with chimney draft entirely, and substitute for it a forced draft under the grate bars, with sealed ash pit? We can then utilize all, or nearly all, the heat now passing up our chimneys to heat our blast. This utilization of waste heat will in itself be a great economy of fuel, and the adoption of the blast will give us more perfect control over combustion, and render greater intensity possible. The charges of fuel may be made thicker and

the particles may be finer, rendering the question of either manual or mechanical stoking simpler. The pressure in the combustion chamber being outward, cold drafts from without will no longer impede combustion, and the occasional opening of the fire-doors will be attended by less unfavorable results.

In the manufacture of iron in the blast furnace, a strong blast of air is injected at the tuyeres to render the combustion of the fuel more complete, and the intensity sufficient to melt the metal reduced from the ore at lower temperatures above the "bosh." For a long time it was supposed that the colder the air forced in through the tuyeres, the better for the quality of iron produced, and that no economy of fuel would be experienced by heating the blast. The unconsumed combustible gases issuing from the throat of the furnace were allowed to escape unutilized, and considered unutilizable. Neilson, however, with a better understanding of the principles of combustion, conceived the idea that these waste gases might be utilized to heat his air before admitting it into his furnace, and thereby accomplish a great economy of fuel. In 1829 he put his plans into operation. They were eminently successful.

At the Clyde works, previous to the introduction of the hot blast, one ton of iron required for its production 8.5 tons of coked coal; but in 1831 hot blast was used, raw coal substituted for coke, and only 2.65 tons of coal were needed to the ton of iron. This was indeed a great saving, but it did not stop there. It was found that as the temperature of the blast increased, so did the economy of fuel. The heat of the blast has been steadily increased, until now it is used at a temperature of 1500 degrees F., and over; and all this produced by what was formerly a totally wasted fuel—the waste gases from the blast furnace.

So thoroughly is this economy appreciated by iron masters, that cold-blast furnaces are now few and far between. The improvement in methods of combustion under steam boilers has not, by any means, kept pace with that attained in blast-furnace practice; and, I may further state, that there has been scarcely *any* improvement in the former. It may seem a bold statement, but I believe it is true, and am willing to father it, that, with a very few exceptions (you can count them on the fingers of one hand probably), all the devices and patents now in use for consuming or preventing smoke under steam boilers, have been essentially covered by patents in England, and elsewhere, in years gone by.

If my statements are correct, and they are borne out both by theory and practice, a great saving in fuel, and, consequently, diminution in smoke, will attend the abolition of natural draft, its substitution by forced

draft, and that heated by the waste products now passing up our chimneys.

Liquid Fuel.

We have thus far discussed the question of fuel as it occurs in the solid state. We have now to turn our attention to other forms of fuel, viz: liquid and gaseous. The only fuel we have in a liquid state that need attract our attention is crude petroleum. This is a natural hydrocarbon, or rather a mixture of many such. It is itself a product of distillation from carbonaceous matter, such as bituminous shales and coal, and is a very concentrated fuel. Many devices have been proposed and tried for its utilization in steam generators, and its high degree of concentration, or large amount of highly combustible matter in small bulk, and the absence of ash and clinker on combustion would seem to recommend it as a fuel—more especially in such cases as marine boilers, etc.; but its extreme combustibility, and the great care required on that account in transportation and storage, render its use as a fuel in all cases hazardous, and in the case just cited, the possibilities are most terrible. I do not think that petroleum will ever come largely into commercial use as a fuel, and will therefore dismiss its discussion with the statement that, were it not for the disadvantages just referred to, it would be a most efficient and manageable fuel.

Gaseous Fuel.

It is the experience of all mechanical engineers, I believe, and I state it on the authority of those eminent scientists, W. J. Macquorn Rankine and W. P. Trowbridge, that the best fuel for generating steam is such as burns with considerable flame; that bituminous and semi-bituminous coals are better for this purpose than charcoal, coke, or anthracite, which burn with little or no flame. Now, all flame is gas in a state of combustion. Solids, on burning, give no flame whatever.

It is the gas, therefore, that we see as flame, and the ignited particles of solid matter within this flame that produce light, and which, at the same time, indicate lack of intensity of the union of oxygen and carbon. Referring again to the Bunsen burner, we see that where the air is properly mixed with the gas it burns with a non-luminous, smokeless, intense flame. Where the air is not so advantageously mixed, as when I shut off its supply at the bottom of the burner, or as is illustrated by the candle-flame or ordinary gas-burner, the flame is highly luminous, the heat generated by combustion is far less intense, and, furthermore, the flame is such that at the slightest provocation it will yield unconsumed carbon or smoke. This luminous flame is what we largely have under

our boilers and in our grates. We can not altogether avoid it in the use of bituminous fuel, as we have not the control of it we have in the Bunsen burner. With gaseous fuel we can have complete control, just as I have over this Bunsen lamp. We have the testimony of the best authorities, that a gas-producing fuel such as ours is the most efficient for the generation of steam, and we have, every day, practical demonstrations of the truth of their testimony. But these same gas-producing fuels are also the greatest smoke producers, and smoke *is* fuel. We can have at best but little control over these gases when burned in the same furnace in which they are generated; hence, the great difficulty our inventors meet with in trying to produce a smokeless fire from bituminous coals.

It is known to gas manufacturers and chemists that, in the distillation of coal to produce gas, the best results are obtained when the distillation proceeds at a comparatively low temperature, and that the higher the temperature employed, the less gas evolved, and the more coke there remains behind. The same is the case in the distillation of wood for the purpose of producing charcoal. On the one hand, gas is the desired product, and on the other, carbon. To manufacture gas, therefore, our temperature must be low. To manufacture coke or charcoal it must be high. We have seen how easily the combustion of gaseous fuel can be controlled in the Bunsen burner. It can be almost as readily controlled on the large scale; but it can not be advantageously controlled, or so economically produced, where the attempt is made to generate and consume it in the same furnace. The conditions best suited for its generation and its combustion can not co-exist. In our ordinary steam generators a high heat is desired. This is inimical to the largest production of gas, and the deficiency of gas, or the presence of gases produced under unfavorable circumstances, is unfavorable to the highest evaporative efficiency or economy of our fuel. For the best results, therefore, our gas should be generated in one furnace, under proper conditions for its greatest production, and burned in another where the conditions for its proper combustion and control exist. The generator will be a cool fire; the consumer a very hot one. Let me call your attention to a practical and successful, as well as an economical, application of this principle in the Siemens's gas producer and regenerative furnace. [This subject was amply illustrated by drawings when the lecture was given.—ED.]

We see here a practical application on a very large scale of the principles involved in the Bunsen burner. The gases and air are mixed before their ignition, and by turning one valve, cutting off a portion of the supply of air, we can produce a luminous or reducing flame, or, by turning it

the other way, a non-luminous, smokeless, and neutral or oxidizing flame at will. The beauty and correctness of the invention, however, does not stop here. The heat generated by the combustion of the gas—I mean that portion of it not utilized in the furnace—is stored up in the checker work of brick below, to heat in its turn the gas and air that are to combine at the next turn of the valves. The heat generated on this principle, though the combustible gases supplied to the furnace constitute only from 25 to 35 per cent. of the total generated, is so intense that it has been applied in many manufacturing industries where the highest temperatures are required, and has given rise to a particular branch of steel manufacture, which was only rendered possible by the intense and easily controlled heat thus furnished - the open-hearth process. Any kind of fuel may be used, even to the better classes of bituminous shales, and the combustion is absolutely without smoke. Other methods of generating the gas, and better ones, too, have been devised—the Tessie Du Motay, which is more economical, and in which fuel containing a larger percentage of ash can be used—the water-gas processes, devised by Strong and others, which at less expense of fuel produce larger percentages of combustible gases, and many others; but my paper is already too long, and I can not touch them in detail, besides, I am dealing with principles, not patents.

The advantages of fuel gas are the perfection of combustion and intensity of heat generated, which can be regulated at will, the possibility of a complete combustion of all smoke, the total absence of all ash or clinker at the point where burned, its very great cleanliness, and extreme economy. No fuel is wasted in starting a fire, and when the fire has done its work, there is none wasted, as at present, since the turn of a valve extinguishes it. This renders its application to domestic use particularly advantageous.

The cost of manufacture of fuel gas on a large scale will vary with the price of coal. As the quality of coal used may be such as is of no market value now, it will be exceedingly cheap. But assuming average price of fuel to be paid, the Siemens's producer can furnish gas ready for delivery at a cost not to exceed six cents per 1,000 feet, which by the utilization of cheaper fuel can be reduced to at least 2 cents, and, it is claimed, to 1½ cents per 1,000 feet.

Prof. Henry Wurtz, who has paid great attention to fuel gas, makes the following estimate of the cost of the Strong water gas: If ⅓ egg coal, at $5.00 per ton, and ⅔ mixture of dust and pea coal, worth $1.00 per ton, be used in the manufacture, it will cost 7.2 cents per 1,000 feet

to put it into the holders. He has, in all cases, left the utmost margins in his calculations, so that this figure is an outside one.

Though the cost per 1,000 feet of the water gas is considerably higher than that produced by the Siemens's and Tessie Du Motay furnaces, the percentage of combustible gases therein contained is much larger, as is also the volume of gas produced from a given amount of coal, so that water gas may be in the end the most economical. According to Percy, one ton of coal free from ash will produce 50,000 cubic feet of gas. If, therefore, we use fuel that contains as high as 20 per cent. of ash, we should get 40,000 cubic feet from each ton by the Siemens's method, while with the Strong process it has been produced at the rate of over 60,000 feet to the ton of a mixture of ⅓ egg anthracite coal and ⅔ slack.

Gaseous fuel is *the most* desirable fuel—the most rational, the most easily managed, and, above all, the most economical, both because of its cheapness, and because its adoption would enable us to use those immense piles of coal dust and slack so unpleasant to the eye in the coal districts, and which now have not only no market value whatever, but which, by their waste, have added to the cost of fuel which we do use. Also because its adoption will enable us to utilize those large deposits of coal containing either too much ash or other deleterious matter (such as sulphur and phosphorus), to allow them to be mined or come to market at the present day. Gas is not only the cheapest, the cleanest, the most economical, but the ideal fuel. It is the fuel of the future, and by future I do not mean one hundred years hence, but only a very short time hence—not years, but months. But individual consumers will not manufacture their own fuel gas any more than they now manufacture their own illuminating gas. It is doubtful if such a course would prove economical; but it will be produced on a very large scale—much larger than is our illuminating gas—by corporations existing for that purpose. It will be distributed through our streets in mains, and to our dwellings and manufacturing establishments by connections with these mains, as is our illuminating gas at the present day, and, probably, eventually through the same pipes. Then, and not till then, will our atmosphere be clear, and our houses clean.

But there are many instances where gaseous fuel, as just described, could not be economically introduced. I refer to steamboats, locomotives, and dwellings and small manufactories isolated from villages of some size. These must still, so far as I can see, continue to utilize solid fuel. But in the case of boilers, the least fuel will be consumed, the

greatest evaporative efficiency attained, and the least smoke produced, the closer their construction fulfills the conditions before enunciated.

The examples of smoke consumers we are most familiar with, were recently examined by John W. Hill, M. E., with the following results: In smoke prevention, he ranks the lowest of the lot at 81.4 per cent. In this furnace there are two grates. The front grate contains the green fire, and may be termed the gas producer or generator. The rear grate contains the incandescent fire, which is to burn the gases evolved from the front grate. In this the horizontal column is divided up to insure a sufficient supply of air where most needed, and its better mixing. The percentage of smoke consumption accredited to this furnace is very far in advance of that usually obtained by ordinary furnaces.

The next on the list is given 82.5 per cent. for its smoke consumption. In this furnace the ordinary combustion chamber is divided longitudinally by a wall—a green fire is started in one, while the other is incandescent—the gases from the green fire passing over the incandescent one. By turning a valve, the direction of the draft is changed; fuel is fed to what was before the incandescent fire, and the products of distillation from this pass over the other fire now in a state of incandescence. The horizontal column is also divided here. The improvement over the first furnace is so slight that it scarcely needs explanation, but is probably due to a greater length of incandescent fire, rendering the chances of escape of unburnt gases less possible.

No. 3 is credited with 87.5 per cent. of smoke consumption. This furnace uses a forced draft over the fire-bed, such draft being caused by jets of steam. Its efficiency is due to the better mixing of the air with the gases, and also the partial heating of the horizontal column due to the injected steam.

No. 4 is called a twin grate furnace, and, like the second, reverses its draft every time fuel is charged, causing products of distillation to pass through first a red hot passage, which heats the gases, and then over an incandescent fire, where more air is admitted. It is somewhat on the gas-producing and regenerative systems. This furnace is credited with 88.3 per cent. of smoke consumption. The gases are pretty well heated before combustion, and the horizontal column is divided, but is cold.

The highest on the list, Mr. Hill has called perfect. This is essentially a gas and coke fire, and the stoking is done mechanically. By this contrivance the solid fuel, before it reaches the fire, has not only become heated, but deprived of all its gas. The fire produced by this, therefore, is a flameless, incandescent fire—the ignition of purely solid substances, as

coke. It is charged, or may be charged as often as desirable, without any opening of doors. The horizontal column is, therefore, under control, and not subject to great variations. The coal, as charged into the hoppers, is subjected to distlilation at a low temperature—this, as we have seen, is the condition most favorable to production of gas—and these gases, in good condition for combustion, pass into the combustion chamber, and are consumed. This furnace, we see most fully, complies with the conditions laid down as necessary to success, and as Mr. Hill has certified, more nearly reaches it than any others examined by him.

But this is an expensive furnace. He places it highest on the list as to cost of application and maintenance, and it shares with another the least favorable position as to durability. As to facility of manipulation, it stands first.

Were a gaseous fuel used as proposed, the furnace so using would stand head and shoulders above all of these in all the points taken by Mr. Hill, viz: smoke consumption, economy of fuel, cost of application, cost of maintenance, facility of manipulation, durability, and evaporative efficiency. The introduction of fuel gas, too, would put an end to the contributions of smoke from the thousands of dwelling chimneys; and the city carts, now employed at great expense in carting off the ashes, could be put to use in the street-cleaning department to good effect. Look at it from any standpoint we will, gaseous fuel must overwhelmingly recommend itself, and the day is near at hand when by its all but universal adoption the atmosphere of our city will be as clear as that of a New England village.

Note on the Preceding Paper.

Mr. Hill's method of examination (as described in the "Report of the Board of Commissioners of the Cincinnati Industrial Exposition" for 1879, page 106) was as follows:

"The observations of smoke issuing from the chimney were taken by two independent observers alternately, every seven and one-half minutes during the trials, except when the darkness, towards the close of trials, prevented an accurate reading of the chimney.

"In reading the chimney gases, the following novel code governed the observers: The entire absence of smoke was taken at 100, indicating the best possible smoke prevention. Faint traces of smoke in the waste gases were taken at 90, indicating results rarely obtained with ordinary

furnace construction and the most skillful firing. Discoloration of the waste gases readily perceptible was taken at 75, indicating a state of smoke prevention considerably above the average of ordinary furnace performance. Ordinary smoke issuing from the chimney was taken at 50, indicating a state of smoke prevention slightly above the average of ordinary furnace performance.

"The ordinary condition of chimney gas with which Cincinnatians are so familiar, was taken at 30, indicating no smoke prevention at all; and the last stage of dense black smoke was taken at 10.

"The notations, except for the entire absence of smoke, are nearly inversely as the weights of free carbon in the waste gases issuing from the chimney."

The trial of each furnace lasted ten hours. The following table (from the report cited, page 113) gives the actual means of the observed readings, and the relative values, to the first decimal place:

	Number of Readings.	Means.	Relative Values.
The Fisher furnace, . .	81	80.1	81.4
The Price furnace, . . .	80	81.2	82.5
The Eureka furnace attachment,	80	86.1	87.5
The Walker furnace, . .	79	86.9	88.3
The Murphy furnace, . .	77	98.5	100.0

It seemed desirable to quote Mr. Hill's method in full, because of the great difficulty in devising and applying a suitable scale for accurate observations on smoke prevention. Other methods, based on the use of smoked glass or polarizing apparatus, so adjusted as to render the column of smoke invisible, have been proposed, but not yet perfected.

R. B. W.

II.—THE GEARING FURNACE FOR BURNING PULVERIZED FUEL.

By L. M. Hosea, Esq.

[Read before the Department, Otcober 13, 1881.]

The furnace to which the name of the inventor, Charles Gearing (of Pittsburg, Pa.) has been applied, is the result of costly experiments pursued for fifteen years, through failure and discouragement, to a triumphant success. The invention is broader than the name implies, being, in fact, a method or process for the perfect combustion of coal, which may be carried out in various forms of furnaces, and is applicable to every branch of manufacturing industry where heat is required, and is, moreover, a perfect solution of the question of "smoke consumption."

In the manufacture of iron, however, the Gearing process possesses a peculiar value; not alone in the mere saving of fuel, great as that saving is, but also in the improvement of the quality and increase in the quantity of iron produced, due to the pure and mild character of the flame resulting from the absolutely perfect combustion of the fuel.

The furnace in which Mr. Gearing's final experiments were made, and upon which were based the observations of Mr. John W. Hill, M. E., hereinafter contained, was a heating furnace erected at the Cincinnati Rolling Mills in July, 1881.

The application of Mr. Gearing's invention involves the use of a vertical chamber called the "generator," occupying the position of the usual fire-box, and opening at the rear directly to the "hearth". where the "charges" or "piles" of scrap iron are placed for treatment. Into this generator, from above, pulverized coal is fed, in connection with a blast of hot air, driven by a minute jet of superheated steam, the pipes being so arranged as to distribute the fuel by expansion uniformly over the grate below. The particles of coal are, by the preliminary combustion, at once deprived of their more volatile constituents, and the resulting gases, together with additional air and steam from a lower or "counter" blast, are carried over the bridge-wall, and the combustion completed over the hearth in contact with the metal.

The air for this purpose is heated by the waste heat of the furnace in flues built in the brick work, the steam being superheated in pipes coiled in the walls of the generator; and the operation proceeds continuously and automatically, the intensity of combustion being exactly regulated to the work to be performed, by valves governing the force of the blasts and the amount of fuel fed to the generator.

In the furnace reported on by Mr. Hill, it will be observed that the grinding and feeding of the coal was performed by a steam engine employed solely for the purpose, and his estimates of cost include, therefore, the entire cost of independent steam power. In commercial use, however, this power can be supplied, usually, without appreciable cost, from the ordinary line shafting of the establishment, and this element of cost omitted.

The following is Mr. Hill's report:

GENTLEMEN:

Agreeably to your instructions, I have made an examination of the performance of the Gearing Hot Blast Furnace, at the Cincinnati Rolling Mills, and have to report to you thereon as follows:

The furnace is attached to an ordinary scrap heating oven, and is arranged to burn finely comminuted coal supplied by a small grinding mill and steam engine placed immediately over the combustion chamber.

The blast is had by means of an ordinary injector with fixed nozzle; a jet of steam supplied from the mill boilers and caused to traverse a system of superheating pipes set in the brick work of the combustion chamber, being employed to move the air.

The air is heated in flues built in the brick work of the oven and is delivered at a high velocity into the combustion chamber from above.

The steam jet propels the air into the furnace at a rate proportional to the delivery of the coal dust and is capable of instant and complete control to regulate the grade of fire.

The ground coal and air enter the combustion chamber through concentric orifices, and the combustion of the coal is practically instantaneous upon its introduction into the furnace.

No air is permitted to enter the combustion chamber except through the blast pipe.

The trial was made August 30th, and embraced the action of the furnace for a single turn with the following results.

Iron.

Five charges of scrap iron faggots were weighed up and heated;

First charge weighed	2299.5	pounds.
Second " "	1930	"
Third " "	1851	"
Fourth " "	1787	"
Fifth " "	1897.5	"
Making a total of	9765	"

Of this quantity there was returned at the end of trial 9044 pounds, showing a loss of iron in heating of 721 pounds or 7.38 per cent.

The average loss of iron in heating with the ordinary furnace is about 11 per cent. of the scrap charged.

Coal.

There was charged to start the fire, of lump coal .	205	pounds.
Of pine kindling 29 pounds equivalent in coal to	14.5	"
Of ground coal to make the heats, eighteen barrels of 170 pounds each, ...	3060	"
Of this latter quantity there was weighed back at end of turn, ...	136	"
Leaving net coal actually burned	3143.5	"

Of the ground coal actually burned during the trial of 11.417 hours, there was expended during a wait of one hour, occasioned by the stoppage of mill to repair the boiler feed pump, (meanwhile the charge, third, was held at welding heat, in the oven), $\frac{8060-186}{11.417}=256.11$ pounds, whence net coal charged was 2887.39 pounds, to which must be added the coal due expenditure of steam in working the grinding mill, which I have estimated at two horse power for 10.417 hours, or, in coal, 104.17 pounds, and coal represented by expenditure of steam in the injector for same period of time, which I have estimated from the following data:

Diameter of orifice .145 inch.

Average steam pressure by gauge 83.7 pounds.

Form of jet convergent of circular section.

The area of orifice was $\frac{.7854 \times .145 \times .145}{144} = .0001147$ sup. feet and velocity of flow in feet per second $.8\sqrt{83.7 \times 2.3 \times 271 \times 64.4} = 1466.32$, and weight of steam discharged for a period of 10.417 hours, $.0001147 \times 1466.32 \times 10.417 \times 3600 \times .23 = 1450.658$ lbs., corresponding to an expenditure of coal of 161.184 pounds; and total coal expended in working furnace for five heats was $\frac{3152.744}{76} = 41.483$ bushels or $\frac{41.483}{4.522} = 9.174$ bushels per ton (2,000 pounds) of finished iron.

The average expenditure of coal in operating scrap heating furnaces for a single turn of six heats, including coal for firing up in the morning, is about 18.615 bushels per ton (2,000 pounds) of finished iron; from which I deduce the saving in coal actually burned by the Gearing furnace as $1.\frac{9.174}{18.615} \times 100 = 50.7$ per cent.; but the Gearing furnace made a ton of finished iron from $\frac{1.0000}{.9262} = 1.0797$ tons of scrap, whilst the ordinary furnace requires $\frac{1.0000}{.89} = 1.1236$ tons of scrap, to make a ton of finished iron, and saving by Gearing furnace in reduced waste of scrap in heating was 4.392 per cent.

Estimating coal in both cases at 16 cents per bushel, then cost of fuel to produce a ton of finished iron by the Gearing furnace was $9.174 \times 16 = 146.784$ cents and by the ordinary furnace $18.615 \times 16 = 297.84$ cents; but with the ordinary furnace there was required 4.392 per cent. more scrap to make a ton of finished iron, the value of which, at $25.00 per ton (2,000 pounds) is 109.8 cents and cost of iron per ton upon equivalent percentage of yield for ordinary furnace becomes 407.64 cents; from which I obtain the actual saving by Gearing furnace, for similar values of scrap iron and coal upon a fuel basis as $1.\frac{146.784}{407.64} \times 100 = 64$ per cent.

Assuming the possible use of slack at 9 cents per bushel reduces the cost of the fuel 43.75 per cent. and increases the gain by the Gearing

furnace 15.75 per cent., and shows a possible reduction in cost of fuel, and increased yield of finished iron, referred to a fuel basis, of 79.75 per cent.

During the trial of August 30th, the flue from the oven to the stack was clogged with cinder, the removal of which was calculated to materially increase the efficiency of the furnace.

The combustion of the fuel was practically perfect, and no smoke was visible at any time during the trial at the top of the chimney.

Owing to numerous delays in the mill during the trial, considerably more time, and consequently more fuel was expended in working the charges than would have been necessary under favorable conditions.

All of which is respectfully submitted.

Very obediently yours,

JOHN W. HILL,
Consulting Engineer.

CINCINNATI, *September* 1, 1881.

Since completing above report, I am in receipt of the following communication, from which it appears that slack at nine cents per bushel was used for trial of August 30th, whence a *saving of nearly eighty per cent.* in cost of fuel and reduced loss of scrap in heating was actually accomplished.

CINCINNATI, *September* 2, 1881.

JOHN W. HILL, ESQ.:
The coal used by Mr. Gearing was slack.

Respectfully yours, C. F. HESSER.

MR. C. F. HESSER:
The slack purchased by you cost 9 cents per bushel.

CAMPBELL CREEK COAL ELEVATOR CO.,
By Hughes.

Remarkable as these results are, as shown by the accurate investigations of Mr. Hill, they were still further improved in the subsequent action of the furnace when the slag hole was cleared and the furnace put into regular service. For a period of two weeks it has turned out seven heats daily, against six from the old style furnace beside it, and this with an expenditure of less than one-fifth the amount of coal consumed in the adjoining furnace. Another important fact to be taken into consideration is, that the coal used in the Gearing furnace was common slack, which is incapable of use in the ordinary heating furnace, by reason of its inferior quality and limited heat-producing power.

In fact, the experiments thus far made, render it all but certain that the Gearing process can be successfully worked by utilizing the refuse coal of the now useless culm banks of the mining regions, which have at present little or no money value.

III.—A SUGGESTION FOR SURFACE DRAINAGE IN CINCINNATI.

By R. B. Warder.

[Read before the Department, February 10, 1881.]

Our gutters are now choked with ice and snow; while both streets and sidewalks are flooded at every thaw. A very simple plan may be proposed for the abatement of this nuisance, requiring no apparatus except a portable steam-boiler, connected by flexible tubing with a narrow covering of boards, some meters in length. Let the boiler be driven to the side of the street near one of the sewer openings, place the cover over a portion of the gutter, and let the steam play upon the ice and snow beneath. As soon as a sufficient channel has been melted, the driver can move on, and another section of the gutter may be cleared as before. When a passage is once well opened, the stream of water caused by the first thaw, will tend to keep it clear.

The details of the plan must be determined by experiment. A given quantity of steam, at the ordinary pressure of the atmosphere, can melt over eight times its own weight of ice. The cover is designed merely to afford a partial confinement of the steam, and keep it in contact with the ice. It may be desirable to attach a strip of coarse bagging along the edge, which would adapt itself to any small irregularities of the sidewalk and street. This cover could be attached to the running gear of the boiler, so as to be drawn with it along the edge of the street; in this case, there should be a lever attachment, by which the driver or fireman could adjust its height. A cheap form of boiler would answer, since no great pressure is required; but instead of procuring special boilers, which would only be needed at certain seasons, it may be best to have some of the Fire Department engines detailed for this purpose, at least for the preliminary trials.

Of course, objections will be raised to any new plans, on the score of economy. I would strongly urge, however, that those most interested in the condition of our thoroughfares should have some experiments made (if winter is not yet over), and let us see whether steam and water power together, will not be far more efficient than the hopeless task of working with pick and shovel, to cart the ice down to the river.

An appliance for the removal of snow by artificial heat was exhibited at the Paris Exposition of 1867, by M. Berthelemon. M. Vaissiére expresses an unfavorable opinion of the use of steam jets for the melting of snow, in "*Annales des Ponts et Chaussees*" (5) **13**, 102; but the subject does not yet seem to be exhausted.

IV.—HOLLAND'S PROCESS FOR MELTING IRIDIUM.

By Wm. L. Dudley.

[Read before the Department, May 12, 1881.]

This metal has been known to chemists for some years, although the public has had but little experience with it; even mining prospectors are, for the most part, unfamiliar with its appearance and properties.

In the year 1803, Smithson Tennant, while investigating the metallic residue which remained when platinum ores were dissolved in aqua regia, thought he had discovered a new metal. Descotils, Fourcroy, and Vauquelin were at the same time examining similar residues, and they also came to the conclusion that a peculiar metal was present; but, however, in 1804, Tennant announced to the scientific world that he had proved the presence of two new metals in these platinum residues, to one of which he gave the name of *iridium*, on account of the iridescence of some of its compounds; and to the other, the name of *osmium* (derived from the Greek, ὀσμή smell), because of the peculiar odor which its volatile oxide possessed.

Iridium is found in considerable quantities in the platinum ores, in the forms of platiniridium, which is an alloy of platinum and iridium, and osmiridium or iridosmine, which is an alloy of osmium and iridium. The platiniridium occurs in grains, and sometimes in small cubes with rounded edges. The iridosmine is usually found in the form of flat, irregular grains, and occasionally in hexagonal prisms.

The geographical distribution of this metal is quite wide; it is found in California, Oregon, Russia, East India, Borneo, South America, Canada, and Australia, and in small quantities in France, Germany, and Spain.

As we find iridosmine, or the so-called native iridium, it is associated with numerous rare metals; viz.: osmium, platinum, rhodium, ruthenium, and palladium, and also with iron and copper.

Iridium possesses a white luster resembling that of steel. In the cold it is quite brittle, but at a white heat it is somewhat malleable. It is one of the heaviest of metals, having a specific gravity of 22.38. When an alcoholic solution of the sulphate of iridium is exposed to sunlight, it deposits an impalpable black powder, which has the very peculiar property of setting fire to a piece of paper saturated with alcohol when brought into contact with the slightest trace of it. When heated in the air to a red heat, the metal is oxidized, but on raising the temperature to about 1000° C., it parts with its oxygen; hence, at a high heat (above 1000° C.)

it is not oxidized. It is insoluble in acids; but is very slightly soluble in aqua regia when heated for many hours.

Iridium is one of the most difficultly fusible of all metals, as will be seen from the following partially successful attempts to fuse it: in Gmelin's Handbook of Chemistry, Vol. 6, we find the results of some of these experiments. "Vauquelin fused it in very small quantity only, on charcoal ignited in a stream of oxygen, and obtained a somewhat ductile globule." This could not have been pure iridium if the globule was ductile, as he states. "Children fused it by his galvanic battery into a white, strongly lustrous, brittle, and still somewhat porous globule of specific gravity 18.68. This globule probably contained platinum (Berzelius). One gram of iridium, heated upon charcoal before Döbler's oxy-hydrogen blow-pipe, fuses into a bright globule, which, however, appears to absorb gas, since, on solidifying, it throws out excrescences, and cavities are formed in its interior."

Platinum, which melts at a much lower temperature than iridium, was first fused by Dr. Hare, of Philadelphia, the inventor of the oxy-hydrogen blow-pipe. He succeeded in melting about two pounds (971 grams) at one time. He was also the first to melt iridium by this means.

As was before stated, the iridium which these old chemists claimed to have melted, must have been impure, containing metals of lower melting points; since one says he "obtained a somewhat ductile globule," and another found the specific gravity to be 18.68; when it is well known that pure iridium, in the cold, is not in the least ductile or malleable, and its specific gravity is 22.38. Alloys of platinum, with a small percentage of iridium, can be comparatively easily melted by the oxy-hydrogen blowpipe.

In a late determination, Violle estimates the melting point of pure iridium at 1950° C., and platinum at 1750° C.

A few years ago MM. Deville and Debray succeeded in modifying Dr. Hare's blow-pipe to such an extent as to obtain more satisfactory results, and in 1870 they prepared bars for the International Metrical System Convention, of 10 per cent. iridium and 90 per cent. platinum; and they successfully melted, in one charge, over 400 pounds of this alloy. This work was carried out under the superintendence of Mr. Geo. Matthey, of the firm of Johnson, Matthey & Co., of London. This alloy is largely in use for making platinum dishes, stills, and crucibles, as the iridium renders the platinum much stiffer and harder, and, consequently, more durable than the pure metal.

This brief outline of the history of methods which have been employed for fusing iridium, brings us to within a few months of the present time.

At this stage of the subject, I have the pleasure of presenting to you the results of the labors of Mr. John Holland, the well-known gold pen manufacturer of our city. Mr. Holland being engaged in the manufacture of what are known as diamond-pointed pens (the points being in fact iridium), it was quite natural that he should be impressed with the desirability of discovering some means of better preparing the metal to meet his own wants in his branch of manufacture. About 18 years ago he commenced his experiments to that end, and never ceased his efforts, sparing neither time nor money in his determined pursuit of the object. At last his labors have been crowned with complete success. He placed a small quantity of the metal in a Hessian crucible, and after raising it to a high heat, he quickly added a stick of phosphorus; when, greatly to his delight, as soon as the fumes cleared away, he saw the liquid mass of metal in the bottom.

It was at this stage of the discovery that the author of this paper became acquainted with it. For certain purposes for which it was proposed to use the metal, it was found necessary to remove the phosphorus which it contained, and this was the first problem that demanded attention. After various experiments, it was found that lime was best adapted to the purpose. The metal, after being melted and cast into suitable shape, is embedded in lime contained in a Hessian crucible, and subjected to a very high heat. This process is repeated several times, each time allowing the metal to remain in the furnace longer than before; when, after four or five such operations, the phosphorus is practically all removed, having combined with the lime. For the want of a better name, and since the metal is rendered much tougher, we have termed this the annealing or dephosphorizing process. The removal of the phosphorus renders the metal slightly porous, but it is as refractory as the original.

Having our time entirely occupied in experimenting with an aim toward practical results, we were unable to do much scientific work; but we are indebted to Prof. F. W. Clarke, of the University of Cincinnati, for assistance in this line. Prof. Clarke has undertaken an analysis of the fused metal, and, although his work is unfinished, he states that it contains about 7½ per cent. of phosphorus.* These analyses are accompanied by peculiar difficulties, since phosphorus is a new element for consideration in the analysis of the platinum metals. This

*Two phosphorus determinations, by Prof. Clarke, gave 7.52% and 7.74%. Mr. O. T. Joslin found 7.58% of phosphorus in the same sample. Osmium was found in traces only in the fused iridium.

offers an interesting subject for research, which at some future time will be pursued.

On casting, we sometimes find the metal slightly porous. The polished surface, to the naked eye, may look perfectly homogeneous, but under the magnifying-glass minute holes may be seen.

In order to obtain the iridium in a convenient form for making pen points, the molten metal is poured upon an iron plate, when the workman immediately strikes it with a heavy iron, thereby flattening it out into a slab of about $\frac{1}{32}$ of an inch in thickness. This slab is broken into small pieces, which are then ground into the proper shape. The grinding is accomplished as follows: a copper wheel, technically called a "lap," about twelve inches in diameter and one-half inch in thickness, revolving at about 3,000 revolutions per minute, is covered with fine emery or corundum mixed with oil. The emery embeds itself into the copper, forming a rough and sharp surface. When the object to be ground is too small to hold in the hand, it is soldered on a piece of brass, which, after the grinding, is dissolved in nitric acid, leaving the iridium free. One ounce of iridium yields from five to ten thousand pen points.

The iridium melted by this process is compact and crystalline; it is harder than the natural metal. Its tensile strength has not been determined as yet. The natural grains of iridosmine are sometimes laminated in structure and are liable to split in the direction of the lamination.

The operation of sawing the metal is accomplished by means of a copper disk, making about 5,000 revolutions per minute, assisted by emery and water. When the metal is ground to a smooth surface by means of emery on a copper wheel, as described, it acquires a good polish, which may be increased by using "crocus powder" afterwards on a similar wheel.

Iridium which has been melted by Mr. Holland's process is nearly as hard as the ruby, which is next in hardness to the diamond. It cuts glass readily; the best files are ruined by attempting to file it. It has about the color of steel. It is not attacked by acids and does not tarnish. The best steel tools fail to make any impression upon it.

A metal with this wonderful combination of valuable properties, will undoubtedly find many uses to which it can be applied with great advantage; and, although we do not propose to mention all its applications, yet it may be of interest to state the result of our experiments with it, as applied to the electric light. Our first experiments were with the incandescent lamp, substituting iridium for carbon, and using it in the open air. As far as the durability of the metal was concerned, the result

seemed favorable; but it required such a large amount of electricity to accomplish the result, as probably to render this method of lighting somewhat expensive.

A short time ago, Mr. W. M. Thomas, of this city, called on Mr. Holland, requesting a piece of iridium to be used in connection with the arc light. Mr. Holland had a small piece prepared, which was substituted for the negative carbon of the lamp. The first experiment was tried for one-half hour, without any apparent effect on the metal. Since then more complete arrangements have been made, and the lamp containing the same piece of iridium has been in operation for over seventy hours without any appreciable loss of metal. The amount of electricity required to maintain it, seems to be much less than for the ordinary lamp. The point of light is always in the same position, and, consequently, can be used in a reflector without the additional clock-work, which is employed to accomplish this result with the ordinary arc light. The light can be made very steady, since the lower carbon, which burns and crumbles away, is dispensed with. When the metal is used where it is subject to intense heat, the phosphorus is removed; but where hardness and non-corrosibility are required, the phosphorus does not offer any inconvenience.

Note on the Preceding Paper.

BY R. B. WARDER.

PROF. DUDLEY has shown that the phosphide of iridium is harder and more fusible than the native metal. It is probably more brittle. These facts remind us of the properties imparted to iron by the presence of phosphorus, carbon, and other non-metals. The physical properties of alloys, and the effect of small additions of non-metals, are subjects of the greatest importance, whether considered in their industrial or their scientific aspect. We need not look further than the discussion on steel rails by Dr. C. B. Dudley, and others (*Journal Frank. Inst.*, 1881), to see that such investigations are still in their infancy, even in regard to iron.

The "dephosphorizing process" for the fused iridium bears a striking analogy to the use of a "basic" lining in the Bessemer convertor, for the removal of phosphorus; in the latter case, however, the steel is melted, and the ingots are consequently homogeneous, while the solid bars of iridium become porous when the phosphorus is removed by heating with lime.

Prof. Dudley states that fused iridium has lately been used for the

points of ruling and drawing pens, stiles, contact points for telegraph keys, and to replace agate in the bearings of analytical balances; it may soon be used also in the place of watch jewels and for bearings of the magnetic compass.

V.—AN ANTISEPTIC CALLED "OZONE."

By Robert B. Warder.

[Read before the Section of Chemistry and Physics, Dec. 22, 1881. Dr. Springer's remarks upon the conclusions reached in this paper are printed on page 13.]

The attention of the Section has already been called to the claims of the "Prentiss Preserving Company," and to their exhibit of meats, fruits, etc, which were said to be preserved by the antiseptic action of ozone. While it is not the purpose of the author either to recommend or to decry any particular business, some reference to the advertisers of ozone is unavoidable. The claims of the company are briefly expressed in the following words from their advertisement: "Ozone—a new process for preserving all perishable articles, animal and vegetable, from fermentation and putrefaction, retaining their odor and flavor." "This preservative * * * * is simply and purely *Ozone*."* The material sold is a dark powder, which is put up in packages of about one pound each. This substance is burned in an air-tight chamber, in which the articles to be preserved are placed. The gas formed by combustion is the real antiseptic, which is called ozone, but the same name is applied also to the original powder. The visitor who inspects the eggs and meats exhibited by the Prentiss Preserving Company is readily persuaded that they use a real antiseptic, and that their claims are at least partly true. The chemist who is asked to believe that *ozone* is produced so cheaply, must feel that his credulity is severely taxed.

The first inquiry which reached me was from Mr. H. C. Freeman, of Illinois, whose habits of practical observation led him to believe that the powder consists of sulphur disguised with charcoal and cinnamon. Dr. E. Osmond, of this city, had reached nearly the same conclusion; and he compares the Prentiss method with "Shourd's New Dominion Process" (said to have been patented in Ontario, Nov. 9, 1868), which depends simply on the fumes of burning sulphur. My own examination led to

*After the reading of this paper before the Section, the last claim was withdrawn; but "Ozone" is still retained as a trade name. The claims have also been modified, in regard to the preservation of fruits.

the following results: The so-called "ozone" is a powder, nearly black, perfectly dry and tasteless, but with a very distinct odor of cinnamon. It contains numerous light-brown particles (under ½ millimeter long), which seemed to be ground cinnamon bark. The powder burns with a blue flame, emitting pungent fumes (which constitute the real antiseptic agent), and leaving black crusts, which also can be consumed by the aid of sufficient heat. It repels moisture, and is not readily wetted.

This substance consists essentially of sulphur and carbon. The percentage of the former constituent was estimated by oxidation with nitric acid and potassium chlorate, evaporation with hydrochloric acid, and precipitation with barium chloride. The fixed carbon was estimated approximately by coking in a porcelain boat, within a closed tube, and deducting the ash and the traces of sulphur which remained in the boat. Actual combustion of the carbon was thus prevented, as the air was quickly driven out by sulphur vapor; but there may have been a small loss of carbon as sulphide. Traces of bituminous matter appeared to be driven out with the sulphur, making black stains on the walls of the tube. The moisture was estimated by heating at 100° Centigrade to constant weight.

Qualitative tests for other volatile inorganic bodies, as ammonium salts, iodine, and mercury, gave negative results.

The general results of the analysis are tabulated as follows:

Moisture (including any volatile oil), ...	.26	per cent.
Sulphur, ...	93.67	"
Fixed carbon, ...	4.63	"
Loss, and carbonaceous matter expelled at a red heat,	1.35	"
Ash, ...	.09	"
Total, ...	100.00	"

In an attempt to separate the carbon and sulphur by dissolving the latter in carbonic sulphide, only 66.80 per cent. of the substance was removed, while at least 80.0 per cent. of the residue was found to be sulphur. It is not likely that so large an amount of the "insoluble modification" of sulphur is present, but that it is mechanically protected by the carbon. This view is also supported by the microscopical examination.

Under a magnifying power of fifty diameters, and with reflected light, the powder is clearly seen to have the form of botryoidal clusters, of an iron-gray color. The spheroids are of nearly uniform size, closely resembling flowers of sulphur, except in color. A few patches that have

escaped the general blackening, are of a beautiful yellow; and here the resemblance is complete. Any one who will examine the "ozone" powder and flowers of sulphur side by side, under a suitable low-power microscope, will find the appearance very characteristic. When the powder is crushed it becomes much lighter, as the spherules are broken and the pale color within is revealed. The carbon, then, is not simply mingled with the sulphur, but is made to adhere to its surface. With a magnifying power of 220 diameters, in bright sunlight, minute black particles are seen upon the yellow background. Lampblack is very finely divided carbon, and this is probably the most available form of carbon with which to disguise the sulphur. It thus appears that the "ozone," as sold, consists essentially of about nineteen parts of flowers of sulphur mixed with one part of lampblack, and scented with ground cinnamon or something closely resembling it.

A sample of distilled water which had been subjected to the Prentiss process was found to be perfectly clear and colorless, with a very distinct smell of sulphurous acid. It had a mildly acid taste, with distinct acid and bleaching reaction on litmus; it reduced potassium permanganate and potassium bichromate, destroyed the blue color of iodide of starch, liberated iodine from potassium iodate, gave a blue precipitate when added to a mixture of potassium ferricyanide and ferric chloride, and yielded sulphuretted hydrogen by the action of zinc and dilute acid. These reactions confirm the presence of sulphurous acid, an active reducing agent, and most conclusively exclude the presence of ozone. A volumetric estimation with potassium permanganate showed the presence of about one-half volume of sulphurous anhydride to one volume of the solution.

Having thus shown that sulphurous anhydride is the chief constituent of the antiseptic gas used in the process described, we may consider three practical questions bearing upon its value:

1st. Are its claims as an antiseptic to be trusted?

2d. Are the foods preserved in a normal condition, with their proper odor and flavor?

3d. Is this preparation superior to pure sulphur, or to a cheap mixture of the substances of which it seems to be prepared?

A complete answer to the first question would require a series of varied experiments, extending, at least, over some months; while the conditions must be under the control of the experimenter during the whole time. Such experiments I have not made. The testimony of interested parties who use sulphurous anhydride, and distinctly advertise that it "is

simply and purely ozone," must be received with all the caution required in such cases, by the ordinary rules of evidence. The antiseptic properties of sulphurous anhydride, however, are well known. Hundreds or thousands of test packages of the Prentiss preparation are sent out daily, and thus the process is subjected to practical tests by numerous consumers. If the claims made are too sweeping, they may still contain a large share of truth. It must be admitted, however, that the antiseptic action of sulphurous acid (like its bleaching action) is said to be more transient than that of some other chemicals. A series of experiments, in which which chlorine, nitric oxide, and other oxidizing agents are compared with sulphurous acid in the permanence of their antiseptic action, may lead to interesting results.

I may add that dilute solutions of tartaric and gallic acids were prepared, one portion of each being subjected to the Prentiss process; these remained quite clear for two months, while flocks of organic growth were observed after a few days in the portions that had not been so treated.

But the mere absence of fermentation and decay is not sufficient to ensure the preservation of articles in their normal conditions. A mummy resists decay for thousands of years. Even in packing-houses, where eggs are kept near the freezing point, they suffer gradual evaporation—the air bubble enlarges at the expense of the fluid contents; and if an egg which can resist decay is kept during the heat of summer, it may require close watching to prevent it from drying up and becoming unsalable. I would recommend, for summer storage, that one or more lots be carefully weighed from week to week, in order that the owner may detect any marked diminution of weight in time to save himself from serious loss. The same principle applies to meat. The shipper or dealer must not merely guard against actual shrinkage in the weight of his stock, but rather he must watch whether it becomes hard, dry, and insipid, losing its juicy freshness. The danger is still greater with some kinds of fruits and vegetables; and if these are kept under water (or solution of sulphurous acid), some of the soluble constituents, to which the delicate flavor is due, must inevitably be removed by diffusion. A single rain will materially alter the chemical composition of a crop of hay. How, then, can we hope for the delicate flavor of a tomato, or green corn, after a month's soaking? While the claims of perfect odor and flavor are evidently quite too sweeping, yet such considerations may possibly lead us to overestimate these inconveniences. The demands of the great public do not recognize that there are pears of more delicate

flavor than the Bartlett, or that green corn when first gathered is far superior to that usually sold in market. While all existing modes of preserving foods from one season to another are more or less inconvenient, or imperfect, the Prentiss method also must be subjected to the test of experience, and abide by the verdict of a discriminating or indiscriminating public, as the case may be.

If sulphurous acid or the Prentiss preserver proves to be of any value, the thanks of the public may be due to the Prentiss Company for the part they have taken in making the antiseptic properties of this substance more widely known. But men of practical business tact will doubtless attempt an improvement on the Prentiss formula, by further experiments with the combustion of sulphur. It is desirable so to regulate the heat generated in the combustion, that the vaporization of unburnt sulphur shall be avoided, and that the contents of the chamber shall not be scorched. The thin coating of carbon, which is spread over the surface of the more inflammable sulphur, may contribute to this end; but that will be readily imitated, if it is found needful to do so.

In conclusion, First, the antiseptic gas stated to be ozone is chiefly sulphur dioxide, the exact value of which still remains to be proved. Second, this is not the only antiseptic. Third, the use of sulphurous acid as an antiseptic is not new. Fourth, sulphur becomes extremely expensive when purchased under the name of ozone at $1.00 to $2.00 per pound.

VI.—LABORATORY NOTES.

By F. W. CLARKE.

[Abstracts of papers read before the Section of Chemistry, March 24, 1881, and published in full in *Amer. Chem. Jour.*, **3**, 197, 201, and 350.]

1.—*Some Double and Triple Oxalates Containing Chromium.*

These compounds were prepared in the University laboratory by E. A. Kebler. The bario-chromic oxalate was obtained anhydrous, hexhydrated, and dodecahydrated; and the strontium compound with twelve molecules of water. All are precipitated as green, silky needles, violet colored by artificial light. Two new triple oxalates were also prepared. The compound $Cr_2Sr_2K_2C_{12}O_{24}$, 12 H_2 O, was a dark green crystalline crust of sp. gr. 2.155. The corresponding barium potassium chrom-oxalate crystallized with six water molecules. All these salts may be regarded as derived from the complex acid

$$\left.\begin{matrix} H.\,C_2O_4. \\ H.\,C_2O_4. \\ H.\,C_2O_4. \end{matrix}\right\} Cr\text{——}Cr \left\{\begin{matrix} C_2O_4.\,H. \\ C_2O_4.\,H. \\ C_2O_4.\,H. \end{matrix}\right.$$

2.—*The Titration of Tartaric, Malic, and Citric Acids with Potassium Permanganate.*

Messrs. Miles Beamer, C. S. Evans, and L. R. Freeman found that citrates, tartrates, and malates were, like oxalates, capable of titration with permanganate solution. The quantitative results obtained were fairly sharp, and encourage further investigation.

3.—*Some New Compounds of Platinum.*

Some new platinum compounds have been prepared in the University laboratory by Miss Mary E. Owens. By the action of an alcoholic solution of potassium cyanate upon an alcoholic solution of platinic chloride, a buff precipitate is formed having the unusual formula $K_2 Pt Cl_5 (CNO), H_2 O$. This compound is soluble in water, but insoluble in alcohol, and its aqueous solution decomposes upon boiling.

Another compound obtained was the sulphocyanoplatinate of strychnia; which forms difficultly soluble crimson needles.

VII.—ALKALIMETRY WITH PHENOL PHTHALEIN AS INDICATOR.

By R. B. Warder.

[Abstract of a paper presented before the Section of Chemistry, March 24, 1881, and published in the *American Chemical Journal* **3**, 55, 232.]

Phenol phthalein, which gives a colorless solution alone or with alkaline bicarbonates, produces a brilliant red when mixed with caustic alkalies or normal carbonates. A simple method is based upon these properties for the estimation of alkalinity and causticity, in the same sample. The solution (which must not be too concentrated) is colored with phenol phthalein, and titrated cold with normal acid until the color is nearly or quite discharged. This quantity of acid, which may be called A_1, is sufficient to neutralize all the caustic alkali and half the carbonate, the remainder being changed to bicarbonate. The solution is then boiled with successive additions of acid. The red color returns as the bicarbonate is decomposed; and the additional quantity of acid required to effect permanent decolorization may be called A_2. The total quantity of alkali is then represented by $A_1 + A_2$, while the causticity is represented by $A_1 — A_2$.

In the ordinary titration of caustic alkalies, this method admits of great accuracy; the influence of a short exposure to the air is readily detected. When a considerable amount of carbonate is present, however, the first end reaction is not sharp, and the reading for A_1 must be taken before the last trace of color disappears. The presence of acetates also impairs

the accuracy, since sodium acetate is decomposed by long boiling, and gives rise to alkaline reaction.

A very dilute solution of sodium carbonate, colored with phenol phthalein, also serves as a *qualitative reagent for CO_2*. A small quantity of this gas destroys the color, which is restored by boiling. As a *lecture experiment*, this is very striking; the carbonic acid of a single expiration from the lungs is sufficient to bleach 100 c. c. of a blood-red fluid. This reagent would seem to be well adapted for the estimation of carbonic acid of the atmosphere, especially where many comparative determinations must be made with little expenditure of time.

VIII.—THE STICKING OF THE TELEGRAPH KEY.

By R. B. Warder.

[Read before the Section of Chemistry and Physics, December 22. 1881.]

The recent invention of the "Cumming Periphery Contact" for telegraph keys (which claims to obviate the "sticking" by diminishing the surface of contact), suggests an inquiry in to the cause of this difficulty; and the object of the present paper is merely to suggest two or three working hypotheses, the complete study of which may require more elaborate investigation.

The lever of an ordinary telegraph key is made to turn upon a horizontal axis. A spring tends to hold the key open, and this is opposed by the pressure of the operator's finger when the key is closed. To avoid needless fatigue in operating, the adjustment is rather delicate, and a small attraction between the terminals would sensibly oppose the force of the spring. The contact is made and broken through two short pieces of platinum wire, whose ends are brought face to face. It is the intention, no doubt, that the electrical contact should extend, as far as possible, over the whole end surface of the platinum terminals. A little consideration will show that it is practically impossible to insure a uniform electrical contact over the whole of two solid surfaces that may be placed together; for the greatest mechanical skill can only approximate to the ideal forms of mathematical precision. One of the surfaces may fail to be absolutely plane, so that the contact is first made at some one projecting point; as the pressure is increased, this part of the metal becomes compressed, so that electrical contact is effected throughout a certain area surrrounding this point, and other projecting points may be brought together. Or, if we consider the surfaces as absolutely plane, they may not be precisely parallel at the moment of initial contact; in

this case, the two circles will first touch at the circumference; the metal will yield slightly to the pressure, so that the actual surface of contact will extend farther and farther from the initial point. In either case, the increased pressure on the key, with increased surface of actual contact, will result in diminished resistance; while the elasticity of the metal will tend to restore it to its original form, and diminished pressure will be accompanied with diminished surface of contact, and increased resistance, until (at the moment the circuit is broken) the resistance is practically infinite. In short, the operations of making and breaking the circuit are not instantaneous but progressive, with variations in the resistance and current strength.

Let us now consider the following questions: 1. Can the sticking be attributed to incipient fusion of the terminals? 2. What must be the electro-dynamic effect of the current through the terminals? 3. What electrostatic result may be expected immediately after breaking the circuit?

First Hypothesis.—The sticking is most troublesome under those circumstances which produce a spark at the moment of breaking the circuit, and this spark is indicative of a very high temperature. It is well known that platinum may be fused in an ordinary blow-pipe flame; the temperature of the flame is high enough, but special precautions are required to impart such a temperature to the wire. If a thin wire is selected, the end may be cut off very obliquely by a pair of scissors, leaving a sharp point. When this is held in the hottest part of a blow-pipe flame, the heat will be conducted away so slowly that the point of the wire is fused to a little globule, which may be readily seen with a pocket lens, or even with the naked eye. Now, if we suppose the end faces of the key terminals to be inclined to each other by a very small angle, the whole current must be concentrated in that portion of these faces where electrical contact can be established. At the moment of breaking contact, we may suppose this area to be reduced almost to a point, as already explained; at this moment the resistance is enormously increased, and the heat thus generated raises a small quantity of matter to incandescence, at the point where the terminals finally part company. Is it improbable that an extremely small portion of each of the terminals should be softened at this moment, so that a filament is drawn out from each surface as they separate, like the filaments produced when two hot rods of glass are touched and pulled apart? If it is possible that even a burr should begin to form on the surfaces, the contact would afterwards be made and broken through this burr, and the conditions would seem to

become more and more favorable for increased fusion, and a prolonged retardation in breaking the circuit.

To test this hypothesis, a key may be selected which has been found liable to stick, and the terminal faces may be examined with a microscope from time to time, to determine whether any change of form can be seen. If the faces are polished, any inequality may be most easily detected by studying the reflection of some long, straight object.

Second Hypothesis.—If the flat terminals touch at a single point, or a very limited area—for example, if the end faces are inclined at a very small angle—the lines of electrical force will be a series of curves, diverging from the point of contact into each of the platinum terminals. In other words, if we consider the whole current as consisting of small elements, each flowing in a separate "tube of force," these tubes of electric flow (which occupy the whole mass of the terminal) are all crowded together at the place of contact; and, within the two end faces, there must be ***nearly parallel currents flowing in opposite directions***, whose electro-dynamic effect is ***repulsion***,* requiring an increased pressure of the operator's finger to maintain perfect contact. To break the circuit, therefore, the finger must be lifted further than would otherwise be needful.

Third Hypothesis.—To investigate to electrostatic conditions, we must regard the end faces as a condenser, at the moment the contact is broken. The mutual attraction will then be

$$F = \frac{E^2 s}{8 \pi d^2}$$

where E is the electromotive force, s is the area of each terminal face, and d is the distance.

If the terminal faces were perfectly true and parallel, d would represent the thickness of an air film, just sufficient to prevent the passage of the spark between the terminals, and this is extremely small. The value of F may therefore be sufficient to interfere with the prompt action of the spring.

To test the last two hypotheses (or some combination of both), I would suggest the construction of a key balance, consisting of a key with large adjustable terminals, in which the electrostatic and electro-dynamic forces may each be subjected to careful measurement. It can then be ascertained whether any of the suspected causes is sufficient to account for the observed difficulty which is experienced; and this will be an important step towards securing a rational plan for its prevention.

*** *The Electrician*, of New York, inadvertently makes a different statement, on page 13 of the January number.**

SCIENTIFIC PROCEEDINGS

OF THE

OHIO MECHANICS' INSTITUTE.

VOL. I. MAY, 1882. NO. 2.

PROCEEDINGS OF THE DEPARTMENT OF SCIENCE AND ARTS.

Meeting of January 12, 1882.

THE "Cumming Periphery Contact" (see pages 8 and 12,) was referred to the Executive Committee for the appointment of an Examining Board, according to Art. VI. of the By-Laws.

Officers were elected for the year 1882 as follows: Chairman, L. M. Hosea; Corresponding Secretary, A. Springer, Ph. D.; Recording Secretary, John B. Heich.

Professor Ormond Stone then delivered a lecture upon "COMETS."

Meeting of February 9.

The Lecture Committee reported that they had made arrangements for a course of six popular lectures, to be given in the Hall of the Institute on successive Wednesday evenings, beginning February 8. The lecturers are Professor T. C. Mendenhall, of the Ohio State University (two lectures), Captain C. E. Dutton, of the U. S. Geological Survey, Professor W. D. Gunning, of Boston, Professor A. Winchell, of the University of Michigan, and Professor A. H. Tuttle, of the Ohio State University.

Dr. A. Springer then read a lecture before the Department on "FERMENTATION."

Meeting of March 9.

Messrs. Warder, Springer, and Anderson, were appointed as a special committee to confer with the "Cincinnati Forestry Club," and to invite the members to organize a *Section of Forestry* in the Department of Science and Arts.

Professor A. G. Wetherby then delivered a lecture upon the "GEOLOGICAL STRUCTURE AND METALLIFEROUS DEPOSITS OF ROAN MT., N. C." The lecturer regarded Roan Mountain as a monoclinal, and stated that

all the mountains and higher ridges of pronounced character, which he had examined in this region, were either monoclinal or synclinal. These mountains he regarded as composed of metamorphosed, stratified or sedimentary rocks. They are occasionally intersected by dikes of igneous rocks, of which the prevailing types are basic; and all the rocks of the region contain a predominance of iron-bearing minerals. Professor Wetherby referred also to the large deposits of magnetic iron ore found here, which occur in beds having the general dip and strike of the rocks containing them.

PROCEEDINGS OF THE SECTION OF MECHANICS AND ENGINEERING.

Meeting of January 19, 1882.

THE relative efficiency of large and small engines and boilers was discussed by several members.

Meeting of February 16.

Officers for the ensuing year were elected as follows: Chairman, Geo. W. Bugbee; Vice-Chairman, J. G. Danks; Secretary, and member of Publishing Committee, James B. Stanwood.

The "RELATIVE ECONOMY OF LARGE AND SMALL BOILERS" was then discussed by Mr. Stanwood.

Meeting of March 16.

Mr. Wm. M. Fisher exhibited a model of an improved "STEAM GENERATOR AND SMOKE PREVENTER," and explained its action. A hollow partition or water-back, made of the same material as the boiler, is hung in such a position as to take the place of a bridge wall, with an opening for the passage of the products of combustion. At one side of this opening, the interior of the water-back communicates directly with the body of the boiler; the other leg passes through the crown sheet up to the water line, and may be further extended as desired. A rapid circulation through the water-back and the boiler was clearly shown in the model. Two or more similar water-backs may be so arranged as to control the circulation of the furnace gases; and experiments with the combustion of paper, in the model, showed a very satisfactory prevention of smoke.

The claims for this device (which is also applicable to the evaporation of brine, sirup, etc.) are smoke prevention, economy of fuel, durability, rapid steam generation, and the prevention of scale.

PROCEEDINGS OF THE SECTION OF CHEMISTRY AND PHYSICS.

Meeting of January 26, 1882.

OFFICERS were elected for the year 1882 as follows: Chairman, Professor F. W. Clarke; Vice-Chairman, Professor Wm. L. Dudley; Recording Secretary, Eliot A. Kebler; Corresponding Secretary, John Hagemann.

Professor R. B. Warder showed a plain spiral diagram, to illustrate the "PERIODIC LAW OF THE ELEMENTS," combining the principal features of Mendelejeff's two diagrams with that of Meyer.

Meeting of February 23.

A communication was received from Mr. Stanley Hatch, upon the suspected contamination of maple sirup by evaporation in contact with galvanized iron. Messrs. Warder, Springer, and Kebler, were appointed a special committee to report on this subject at the next meeting.

Professor Warder read a paper on the "GHOSTS BY REFLECTION IN THE OBJECTIVE OF A REFRACTING TELESCOPE," and a note on the "FLOW OF LIQUIDS ON THE SURFACE OF A BURETTE."

Professor F. W. Clarke spoke upon "BASIC AND DOUBLE SALTS AND WATER OF CRYSTALLIZATION." In magnesium sulphate, one molecule of water can be reckoned as constitutional, and then the structure can be written thus:

$$HO-Mg-SO_4-H.$$

The corresponding double potassium salt is

$$K-SO_4-Mg-SO_4-K.$$

Both of these salts, as regards water of crystallization, are now hexhydrated; as are indeed nearly all magnesium compounds.

The following formulæ illustrate the structure of some aluminum and bismuth salts:

$Al_2(SO_4)_3$ becomes $SO_4{=}Al-SO_4-Al{=}SO_4$.

Anhydrous alum, $AlK(SO_4)_2$, becomes $K-SO_4-Al{=}SO_4$.

Basic alum, $Al_2O_2(SO_4).K_2SO_4.2H_2O$, becomes $2K-SO_4-Al{=}(OH)_2$

$$Al_2(SO_4)_3.Al_2(OH)_6 \text{ becomes } \begin{array}{ccccccc} (OH)_2 & & OH & & OH & & (OH)_2 \\ \| & & | & & | & & \| \\ Al & -SO_4- & Al & -SO_4- & Al & -SO_4- & Al. \end{array}$$

The complicated salt $Al_2(SO_4)_2(OH)_2.2Al_2(SO_4)(OH)_4$, is equivalent to a double molecule of the following structure:

$$\begin{array}{ccccc} (OH)_2 & & OH & & (OH)_2 \\ \| & & | & & \| \\ Al & -SO_4- & Al & -SO_4- & Al. \end{array}$$

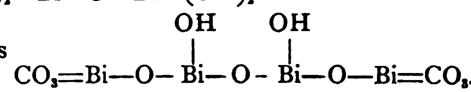
For bismuth salts the subjoined examples will suffice:

$BiO.NO_3.H_2O$ becomes $(HO)_2{=}Bi{—}O{—}NO_2$.

$(BiO)_2\,SO_4.2H_2O$ becomes $(HO)_2{=}Bi{—}SO_4{—}Bi{—}(OH)_2$.

$Bi_2O_3.2H_2O$ becomes $(HO)_2{=}Bi{—}O-Bi{=}(OH)_2$.

$2(Bi_2O_2.CO_3).H_2O$ becomes

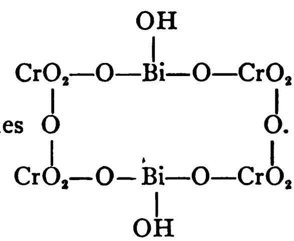


$2(Bi_2O_2.CrO_4).Bi_2O_3$ becomes

$$CrO_4{=}Bi{—}O{—}Bi{=}O_2{=}Bi{—}O{—}Bi{=}O_2{=}Bi{—}O{—}Bi{—}CrO_4.$$

And finally the peculiar salt to which is given the empirical formula

$Bi_2Cr_4O_{15}.H_2O$, becomes



Meeting of March 23.

Professor F. W. Clarke exhibited the NEW MINERAL from near Gunnison City, Colorado, described by Mr. N. W. Perry, at the November meeting, 1881.* This mineral was given to Mr. Perry by an assayer at Gunnison, who stated that a considerable quantity of it could be found at a point about twenty miles south of that place. It is massive, deep purple in color, of a soft earthy texture, and with a specific gravity of 2·85. It is associated in the specimens under examination with a crystalline calcite, which permeates the new mineral also. Analysis by Mr. E. A. Kebler gave the following results:

Fluorine,	31·96
Calcium,	45·91
Silica,	6·02
Alumina,†	5·21
Soda,	·74
Carbonic acid,	5·61
Loss (oxygen),	4·55
	100·00

*These PROCEEDINGS, page 12.

† With a little iron.

These figures, combined as is usual in fluoride analyses, come out as follows:

CaF_2,	65·60
$CaCO_3$,	12·75
CaO,	10·02
SiO_2,	6·02
$Al_2O_3(+Fe_2O_3)$,	5·21
Na_2O,	·74
	100·34

Reckoning the $CaCO_3$ as an admixture, and recalculating the remainder, the composition of the new mineral itself becomes

CaF_2,	74·89
CaO,	11·44
Al_2O_3,	5·95
SiO_2,	6·87
Na_2O,	·85
	100·00

This, ignoring the soda, agrees fairly with the formula $7CaO.2Al_2O_3.4SiO_2.32CaF_2$. Possibly an examination of purer material might lead to the simpler ratios of $4CaO.Al_2O_3.2SiO_2.16CaF_2$.

A study of the locality itself is needed, together with analyses of different specimens from different parts of the vein. Doubtless the mineral is an alteration product derived from fluor spar.

Professor Ormond Stone presented some "NOTES ON THE COMPUTATION OF PERTURBATIONS."

The Special Committee appointed in February made their report upon the "CONTAMINATION OF MAPLE SIRUP FROM EVAPORATION IN GALVANIZED IRON."

Professor Warder called attention to the "ADULTERATION OF CANDY" sold in Cincinnati, and especially to the use of terra alba. Mr. C. S. Evans had found 30·3 per cent. and 40·5 per. cent. of ash respectively in two samples. Action of the Cincinnati Board of Health was deemed desirable.

Dr. Springer then read a paper on "FERMENTATION, AND THE CULTIVATION OF MITIGATED VIRUS," and discussed the thories of Grawitz, Pasteur and other scientists, relating to the probable causes of the observed facts; he agrees with them in believing that animal cells that have been attacked by the weaker virus transmit to subsequent cells the power of resistance for unmitigated virus.

IX.—REPORT ON COMBINED FARM AND TRACTION ENGINES.

By J. C. Hoadley, M. E.

[The trials of engines conducted by Mr. Hoadley and published below, were made at the Ninth Cincinnati Industrial Exposition, which was held in 1881 under the direction of a Board of Commissioners representing jointly the Chamber of Commerce, the Board of Trade, and the Ohio Mechanics' Institute. A large part of the observations were made by volunteer assistants, from the Department of Science and Arts, who responded to an invitation of the Chairman, mentioned on page 6 of these Proceedings.

The Publishing Committee is indebted to the courtesy of the Exposition Commissioners for the use of electrotype illustrations, with the privilege of the simultaneous publication of a part of their Report.]

PART FIRST.—ECONOMY TRIAL.

The three competitors drew the following order of succession:

1. Frick & Co.,
2. Geiser Manufacturing Co.,
3. Huber Manufacturing Co.,

And promptly presented their engines on the three successive days assigned to them, respectively: September 28, 29, and 30; and on the sixth October for the Field Trial.

DYNAMOMETER.

A friction dynamometer, or Prony's brake, of simple construction, was improvised and used with all the engines. A pulley with very heavy rim, 125·2 in. circumference, 4 in. face, keyed on one end of a shaft, 2·9375 in. diameter, 48 in. long, carried in two inverted drop-hangers fastened to the floor, served as the friction pulley. A belt pulley, 124·925 in. circumference, 8 in. face, placed on this shaft, near the other end, but between the bearings, received a belt from the engine. A beam of ash, 11 ft. long, 4 in. wide, by 8 in. deep in the middle and 4 in. at the ends, fitted to the circumference of the brake pulley for about 18 in. at the middle of its length, served as a brake-beam. A strap of band iron, 3 in. wide by 0·12 in. thick, terminated at the ends by screws 0·87 in. diameter, lined at intervals with maple blocks, formed the binding strap—the screws being carried up through the brake-beam, so as to cause the strap to embrace the lower half of the brake pulley. A trough, like a grindstone trough, with an inlet and outlet pipe, and a casing of boards on the rising side of the brake pulley, to keep the water from being thrown out, with streams arranged to run on top of the pulley,

through holes in the brake-beam, served to disperse the heat by a regulated flow of water.

A dash-pot, 5 in. diameter, about 8 in. long, with circulating pipe, ¾ in. diameter, from bottom to top, having a cock to regulate the circulation, and a loosely fitting piston, answered well to moderate the vibrations of the brake-beam, by integrating all transient and opposite impulses, giving, as a net result, a slow upward or downward motion, due to the algebraic sum of such impulses. Near each end, a stop rising from the floor, about 1·25 in. below the bottom of brake-beam when the latter was level, served to arrest the ascent or descent of its weighted end, if allowed to move so far in either direction from the level position. The entire weight of the balanced brake was counterbalanced by an equal weight, acting by means of a rope over suitable pulleys. The weight which constituted the load to be lifted by friction, was placed on the piston rod of the dash-pot, at a horizontal distance from a vertical line through the axis at the brake pulley of 5·25 feet, giving a circumference of 33 ft., a convenient number, as each 1 pound carried by friction during 1,000 revolutions represented one dynamic horse-power. A clock or revolution counter, placed on the brake shaft, and another on the engine shaft, recorded the number of revolutions of each, and, by comparison with the circumference of pulleys, measured with a steel tape, gave the slip, or "creep," of belts here about 1 per cent.

This load, alike in all of the three trials, was made up as follows:

Piston and piston rod of dash-pot, . .		14·25 lbs.
Sleeve, nuts and washers, to support weights, .		3·25 lbs.
1 iron weight, ...	25 lbs.	
1 iron weight, ...	25 lbs.	
1 iron weight, ...	10 lbs.	60·00 lbs.
Total, unbalanced weight, .		77·50 lbs.

At each revolution of the brake pulley, while this weight of 77.5 pounds was sustained in a level position of the brake-beam, by friction at the surface of the pulley, power equal to $77\cdot5\text{x}33=2557\cdot5$ foot-pounds, was given off by the engine to the dynamometer, and each revolution *per minute* represented—$\frac{77\cdot5\times33}{33000}=0\cdot0775$ H. P. dynamic. Reciprocally, 12·9032, or, roughly, 12·9 revolutions per minute represented 1 D. H. P.

The whole apparatus being new, neither the concavity in the brake-beam nor the maple blocks in the binding strap fitted perfectly to the pulley, and the surface of the pulley was somewhat rough, so that a little wearing away of both the wood and the iron was constantly going on,

making it necessary to tighten the binding strap from time to time, in order to keep the weights from descending. If this tightening could have been done regularly, and in just the right degree, the brake-beam might have been kept quite steadily in the true, level position. This desirable result was sometimes very nearly obtained for hours together. Often, however, a little nervousness or indiscretion on the part of the attendant would give rise to considerable vibration, sometimes as rapid as the dash-pot would permit, and occasionally disastrous in their consequences. When the weights were descending, a part of the load rested on the water in the dash-pot, and its force was expended in driving water upward through the circulating pipe and the leakage at the piston, and the engine, to that extent relieved of its load, was exerting less power.

When, on the other hand, the weights were ascending, the resistance of the water in the dash-pot added indefinitely to the load, up to the whole weight of the atmosphere on the piston area, equal to $19{\cdot}635 \times 14{\cdot}7 = 288{\cdot}6$ pounds.

This is 3·7 times the regular load, and of course much more than either of the engines could produce even for an instant, and explains how an injudicious tightening of the binding strap would cause the almost instantaneous arrest of the engine, which took place once with one engine and repeatedly with another. From the two first engines tested friction cards were taken with a ten-pound spring (the steam being throttled), which agreed very well with the observed difference between the indicated power of the engine and the dynamic power imparted to the brake. In the third case no friction card was taken on account of the lateness of the hour of starting, nearly half-past five in the evening, the absence of an assistant (devolving more arduous duties on the rest), and other circumstances. The observed difference between I. H. P. and D. H. P., as seen at lines 135 and 136 of Table I., was about the same as in the other engines.

GENERAL ARRANGEMENTS OF THE TRIALS FOR ECONOMY OF WATER AND FUEL.

Feed-Water. For keeping a record of the feed-water used, two casks were provided, each set on a pair of 1,000 lb. Fairbanks' scales, generously lent by the agent of the manufacturers for the purpose. It was intended to draw from the two casks alternately, in the usual manner, recording the weight before and after each draught; but for some reason of supposed convenience all the water was weighed in one cask and

poured into the other, from which it was drawn. I have, however, no reason to doubt the accuracy of the log, which was kept by two careful and trained observers, Mr. Walter Laidlaw and Prof. R. B. Warder. A scale, graduated to inches and tenths of an inch, was attached to each glass water gauge, and the height of the water was observed and recorded every quarter of an hour, and very carefully at the beginning and end of the trial, and any observed difference of level allowed for. The temperature of feed-water was noted every fifteen minutes, and the mean temperature, entered in Table I., line 126, is the arithmetical mean of all observed temperatures.

The great disparity between the steam expended and the water used in the economy trial of the Frick engine, is to be explained by a leakage of steam at the valve-rod stuffing-box. At 3 h., 45 m. P. M. the screw stuffer jarred off and the packing was blown out.

For a time, while efforts were continued to repack the stuffing-box, the loss of steam was very great; and even after the stuffer was screwed on over the empty stuffer, the constant leakage was very considerable. The whole duration of this unfortunate leak was 3 h., 36 m., 35 s., equal to 72 per cent. of the whole duration of the trial, and is sufficient, in my judgment, to explain the excessive consumption of water compared with the steam expended.

The following considerations will, I think, confirm this opinion. For convenience I have presented the data in tabular form. The rate of evaporation per square foot of water surface, expressed in cubic inches of steam, per square foot of surface of water per second, will be found at the end of Table I.

It will be observed that the area of water surface at the *mean* water level, line 312, is a little different from the area at *normal* water level, line 65, 1·1 sq. ft. *more* in the Huber engine, 4·2 sq. ft. *less* in the Frick engine, and 1·6 sq. ft. *less* in the Geiser engine. Huber's rate of ebullition is much the highest, but his water surface is all of nearly equal value, while in both the others, the fire-box and the first foot in length of the flues do far more than the average work of the whole boiler, and their rate of ebullition at and near the fire-box may be as rapid as Huber's mean rate. But the Frick and Geiser boilers are so similar that they may justly be compared in this respect. The Frick has but 20·54 sq. ft. of fire-box heating surface; the Geiser has 26 sq. ft., the former being only 79 per cent. of the latter. The Frick has but 12·6 per cent. of its total heating surface in the fire-box; the Geiser has 22·8 per cent. (ll. 16, 19). It is, therefore, probable that the hot gases of the combustion

escape from the fire-box and enter the flues at a higher temperature in the Frick engine than in the Geiser, and that the active disengagement of steam from the surface of the water, in a word, the ebullition, may be no more active in the former than in the latter. There can not, at any rate, be much difference, since they differ in the mean rate of ebullition only in the ratio of 9:8.

Such being the case, it is just to assume that the ratio of water used to steam expended in the Geiser engine may be properly applied to the Frick. This was the ratio of 35·1 (l. 139, Table I.) to 27·38 (l. 123), an excess of 7·72 lbs. (l. 141), equal to 28·19 per cent. (l. 142). Applying this ratio, we must add to 30·52 (l. 123) 28·19 per cent. of itself=8·6 lbs., making 39·12 lbs., being the quantity of water probably really used by the Frick engine per indicated horse-power per hour. The excess of the actual quantity used, 47·94 lbs.,=8·84 lbs., represents the waste at the valve stem stuffing-box, which had to be evaporated, increasing by about 22 per cent. both the rate of ebullition and the consumption of coal.

Aside from this, the run of over five hours was performed with perfect regularity and ease. The plunger of the pump attached to the cross-head was removed during the trial, and the boiler was supplied by the donkey steam pump—a little increasing the expenditure of steam. The engine ran with quite remarkable steadiness, although only very slightly blocked at the wheels on the floor—the result of excellent counter-balancing, and of the central position of its cylinder. Counter-balances opposite the crank-throw doubtless contributed something to this steadiness. The clearance, 10·18 per cent. of stroke at the end of cylinder nearest to crank, and 12·18 per cent. at the other end, or mean of 11·18 per cent. is excessive, requiring too early exhaust closure if sufficient compression is to be obtained; but even as the clearance is, if the return stroke had been something like equal in economy to the forward stroke, this engine would have surpassed all its rivals in economy of steam.

Fuel: Manner of Conducting the Trial. Steam pressure having been raised to about the limit at which the safety-valve was set—all things being in readiness—fire was drawn, flues were cleaned, fire-box, ash-pit and smoke-box were cleared, and all the partly burned coal, ashes and refuse were taken away. Four pounds of dry shavings and twenty pounds of fine strips of dry white pine were given to each engine for kindling and heating the coal, and for raising the steam pressure, which had fallen off during the process of cleaning, up to the normal, and insuring a fire sufficiently well ignited to maintain regular pressure under

the appointed load. At a given signal, fire was set with a match; and at another signal, at a time carefully noted by at least two observers, the starting valve was opened and the trial began. As soon as the engine started, the binding strap of the friction brake was tightened, and the exact time when the weighted arm of the brake-beam rose from its stop was also noted. The middle of this period between engine running light and engine fully loaded was called the "true start," upon the assumption that the application of frictional resistance was uniformly progressive during this period.

Coal. This was good, dry Youghiogheny, semi-bituminous, having about 11 per cent. of refuse. No selection was allowed, but only lumps were used. All coal was brought from the cellar, where it was stored, to the engine by men employed for that purpose by the Commissioners, under the direction of Mr. Harry M. Lane, Superintendent of Machinery Hall. A box three feet square, with sides and a back, but open in front, was placed on another pair of Fairbanks' 1,000 lb. scales, similar to those used for water, filled with coal, weighed, and the weight was recorded. From this box coal was taken at will by the fireman, the weight remaining being taken after every firing, or at any rate very frequently.

In a short test, of only five hours' duration, extreme accuracy is required, and is the more easily attainable in that the close attention demanded for extreme accuracy is practicable for so short a time. At the expiration of the time, upon a given signal, steam was shut off, the engine stopped, and the time of stopping was again carefully noted. The fire was drawn and quenched, and fire-box, ash-pit, flues and smoke-box cleaned, and all that was withdrawn was set away in a closet, under lock and key, till the next morning, when the unburned and half-burned coal and ashes were weighed, and the true quantity of coal burned, of refuse left, and of combustible burned, were determined by Mr. Walter Laidlaw and myself. The reading of the revolution counters before and after the run gave the number of revolutions actually made by both engine and dynamometer. For fear of accidents to the counters, the speed of both was taken with an ordinary speed counter during one minute, every quarter of an hour. A comparison of the relative speed of engine and dynamometer with the relative circumference of their respective pulleys, also served as a check on the reading of the counters, which, besides, were taken independently by three observers, and compared, while there was still opportunity for revision.

INDICATOR DIAGRAMS.

A Crosby indicator was used, and was found to be well adapted to the speeds which obtained, and very convenient to manipulate.

Diagrams were taken at intervals, not at uniform intervals, since there was no sufficient corps of assistants at hand to work up a great number of diagrams. This was the less necessary since the load was nearly uniform—quite uniform when the brake-beam was kept steadily level, as already explained.

This beam was watched, cards were taken when it was level and at rest, when it was slowly subsiding or slowly rising.

A very considerable number of diagrams were measured with the Amster polar planimeter, in the most obliging manner, by Mr. Frank Lederle, a graduate of the Stevens Institute of Technology. To each line so measured was given a "weight," corresponding to the number of perfect lines on the same card which it fairly represented; the resulting mean effective pressure found for this line was multiplied by its assigned weight, and so a mean was obtained fairly representing a considerable number of independent lines. The diagram which best agreed with this mean was selected to represent the mean card, and the normal lines drawn upon it truly represent the mean within the limits of accuracy aimed at. Such complete details of the teaching of these diagrams will be found in Table I., that little need be added. Two wide fields of investigation have, however, been left untouched, namely: the effect of the inertia of the reciprocating parts in modifying the horizontal pressure at the crank, and the influence of the length of the connecting rod on the distribution of tangential pressures, or rotative effect, on the crank. I can only allude to these interesting and important investigations here, as the time necessary for their complete development would far transcend anything contemplated in undertaking these trials. I earnestly commend them to the careful consideration of the parties interested.

A new Crosby steam gauge of great delicacy, which had been twice compared with a mercury column just before I left home, was used on all the engines tested, detached sufficiently to avoid affecting the resilience of the spring by heat. An unfortunate fall at the Exposition having caused some doubt of its accuracy, it was tested twice; first by the Lane & Bodley Company, and again by Wm. Kirkup & Son. The steam gauges attached to the engines, and much affected by heat, all show several pounds higher pressure. See ll. 88, 89, Table I.

But little remains to be said respecting the separate tests; but some description must be attempted of each engine, and of its behavior under

trial, as well as of the peculiar incidents which in some cases marked its performance.

FRICK & CO.'S ENGINE.

Most of the important dimensions of this fine engine will be found in Table I. Its framing is remarkable for the completeness with which the boiler is relieved of all strains resulting from the action of the steam engine or running gear. A frame of channel iron, 2x5 in., with suitable girders, wide enough in the clear to allow the fire-box to drop freely into it, is narrowed by an oblique offset on each side, about two feet forward of the fire-box, to a width in the clear of about eighteen inches. A saddle at the forward end, and a band extending around under the fire-box near the hind axle, support the weight of the boiler without confining it. Plates of iron three-eighths of an inch thick, riveted to the side channel plates of the frame, and extending a little below the frame, to form jaws for the hind ovals, extend high enough to support an arch spanning from side to side, to sustain the weight of the engine bed-plate at its hind end. At the front end the bed-plate rests, by an expansion joint, on a casting riveted to the boiler. The bed-plate, which is in the form of a trough, comes up to a level with the axis of the engine, and its top flange forms the lower slide; the bottom of the near plate of the cross-head being on a level with the axis of cross-head pin.

The bottom and one side of the crank-shaft boxes are formed in the solid bed-plate, and are lined with Babbitt metal, as is the cast-iron cap. The other side of the bearing is formed of a bronze cheek-piece, held up to its work by two set screws, and capable of being drawn back far enough when its set screws are withdrawn to be lifted out, and so liberate the shaft.

The arrangement of riding springs is ingenious and admirable, but not easy to describe without drawings. The connection between the gearing and the driving wheels, by means of which the riding springs are allowed free play, and all shocks are taken off the gearing, is very meritorious. Springs in the chains of the steering gear also relieve this gear from severe shocks. An independent pump is useful when the engine is not running. The gears of the equalizing gear are tightly cased, and all the gears are well protected from dirt.

There is a convenient brake, for moderating the speed on going down hill, particularly useful when the engine is drawn by horses.

This engine everywhere shows careful study, skilled adaptation of all parts to their office and to each other; and meritorious originality, conjoined with critical selection of approved forms and methods.

A week spent in adjusting the valve, and in equalizing its motion, with the aid of an indicator, might have reduced the quantity of steam expended by as much as 16 per cent., and so have brought the engine up to the foremost rank in point of economy of heat, as it certainly is in all that relates to design and construction.

Trial of the Frick Engine. This trial was attended with few noticeable incidents, and calls for little comment.

The untoward jarring loose of the valve-rod stuffer and the blowing out of the packing have already been commented on at some length. This did not in the least affect the result of the trial, or the relative standing of the engine, as will be seen by consulting ll. 121, 122, 123, 156, 157, 158, 159, 170, 171 and 172, Table I., and the diagrams, which are all quite independent of the loss of steam at the stuffer of the valve-rod. Notwithstanding this loss, and the harder duty thereby imposed on the boiler, this boiler was, as might have been expected from its much greater heating surface, the most efficient one tested, as will be seen by referring to line 179, of Table I.

The heater of this engine was also the most efficient, having an efficiency, derived from heat rejected by the engine, no less than 7·37 per cent., of the efficiency of the boiler.

The speed was noticeably uniform, and the entire run was exempt from all accidents, save the loss of the valve-rod packing.

THE GEISER MANUFACTURING CO.'S ENGINE.

This excellent engine, designed by Mr. F. F. Landis, and built under his superintendence and in accordance with his patents, by the Geiser Manufacturing Co., amply repaid long and careful study.

It has a semi-frame, not so complete as that of Mr. Frick, but serving to carry the whole fire-box end of the boiler, and to sustain the driving wheels and gearing. Cast-iron side pieces replace the three-eighths plates of the Frick engine. The cylinder is on the "off" side of the boiler, and is connected with the crank-shaft boxes by a frame or bed-plate resembling the Corliss bed-plate. The slides are not fitted solid in this bed-plate, in the usual manner, but are adjustable. The advantages of this arrangement can best be ascertained by trial during several years.

A noticeable feature is the reversing gear—a modification of the old plan of revolving the eccentric on the shaft from the proper position for going ahead to the proper position for going backward, and back again. The eccentric is locked to the shaft by a hook. This hook is on a disc

keyed upon a shaft, and this shaft is connected with the eccentric by gears, so that they can never change their relative position except as the gears are turned. A hand crank, by means of pulleys, and a short 2 in. belt, communicates motion at will to the hook-disc, its shaft and its gear, and by means of this gear and the one on the eccentric, so that the position of the eccentric is reversed, and the hook (which is double-sided, like the head of a dart) is brought invariably to engage with its notch in the eccentric disc at the right moment. As a mere reverse motion, nothing could be better; but it lacks the important function of a variable expansion gear. A shifting link is a good reverse motion, and much more.

The driving wheels have wooden spokes, very cleverly arranged for keeping them always tight. Taken in connection with the casing of the equalizing gears, the hubs look heavy, and the engine certainly is heavy, as will be seen by reference to lines 289, 290, 291, 292 and 293, Table I., although ten per cent. lighter, without fuel and water, than the Frick engine.

The equalizing gear is singularly interesting. It is on the hind axle, and composed entirely of spur-gears, which are necessarily strong. There are three pair of pinions, running in sockets upon the ends of their teeth, each pair of sockets overlapping sufficiently to permit the pair of pinions which run in them to engage each other for half their length, to reverse their motion; and each one overlapping its contiguous internally toothed gear sufficiently to allow the other half of the length of each pinion to engage with its gear; one of these gears being, of course, on the adjacent driving wheel, and the other keyed to the axle to which the driving wheel on the other side is also keyed. All this gearing is cased up almost as securely as a hunting-case watch, and runs in most abundant and perfect lubrication; yet all can be taken off, laid out on the floor, examined, and replaced in a few minutes, with the least possible trouble.

The flexible and elastic connection between the gearing and the driving wheels, admitting of all useful freedom of motion, and softening all shocks, such as from striking stones in the road, is apparently all that could be desired. There is a convenient and effective brake, for controlling the engine on descending ground without steam, as when drawn by horses.

The diagrams show admirable skill in distributing the inequalities of motion of a single slide-valve, so as to give good expansion, release and compression, combined with reasonably good admission. The latter is

a little tardy on the return stroke. The initial pressure, which is almost always lower at this end (the end farthest from the crank, the "forward" end of a locomotive engine) on account of the higher piston speed at this end, due to the vibration of the connecting rod, accelerating the piston at this end and retarding it at the other end, is here depressed to an unusual degree, so that the mean effective pressure of the return stroke is actually 10·2 per cent. *lower* than that of the forward stroke—a very unusual occurrence.

Clearance is very small, only 6·25 per cent. at one end and 7·75 per cent. at the other, a mean of 7 per cent. On the whole, it would not be easy to point out a way to improve the steam distribution shown by these diagrams in any great degree, with a single slide valve, and no variation in either expansion or compression.

The result is seen in the consumption of water, and in the steam expended per horse-power per hour, 27·38 lbs., which is remarkably low for a slide-valve, throttling engine, without steam-jacketed cylinder, and would not be thought discreditable to many a large, costly engine, with many refined appliances for saving heat and a good reputation for economy.

In common with all the competing engines, the boiler of this Geiser engine is without clothing of any kind.

Trial of the Geiser Engine. The start was rather late—4 h., 8 m., 57 s., P. M.—but excellent friction cards were first taken, according to which the power consumed in friction was 2·74 H. P. By difference of I. H. P. and D. H. P., 24·22—21·52=2·74, it was substantially the same. The engine ran steadily, almost as steadily as the Frick engine, save a very slight lateral motion, due to the one-sided position of the cylinder, which, by combination with the longitudinal motion, produced a just noticeable gyratory motion. The feed pump attached to cross-head was used, and the independent pump was not started until after the close of the trial. Not a single incident in the least degree abnormal occurred during the trial, until, at 9 h., 1 m., 30 s., just 4 h., 52 m., 33 s. after starting, and just 7 m., 27 s. before the end of 5 full hours, the engine almost instantly stopped. Just 3 minutes later, at 9 h., 4 m., 30 s., the safety valve lifted with a sharp "pop!" showing that the engine did not stop for want of steam.

Examination soon revealed that its stoppage was not due to any breakage or disarrangement of any of its parts, and subsequent investigation revealed the cause.

As the run was thought by all to be about terminated, the man who

was attending to the brake left his post to take part in the preparations for drawing the fire after the close of the trial. Before leaving, he was seen by Mr. Harry M. Lane to give a good pull to the wrench in the direction of tightening the binding strap—as this man himself says, to prevent the loaded end of the brake from subsiding, by the slight wear of the parts already explained. Tightening the binding strap a little too much, the weighted end rose until the other end struck its stop, when the resistance thus suddenly increased became greater than the engine with full steam pressure and full throttle could overcome, and it of necessity stopped almost instantly. The time was so nearly up, and the engine was so obviously not to be blamed for an accident to the dynamometer not resulting in the least damage to the engine, that the trial was pronounced closed, and the fire was drawn, quenched, and put away till morning.

The engine suffered a little loss by the burning away of some coal during the few moments of indecision before directions to draw the fire were given; but this loss must have been small, as the time was short, not exceeding two minutes.

The water was a little low at stopping, but the deficit, 75·7 lbs., was pumped in by the donkey pump, first started for that purpose; the steam pressure was taken after the water was brought to the same level as at starting, and due allowance was made for difference of pressure.

I have been thus explicit because this awkward stop has given rise to some comment, and may give rise to more; and because I am fully satisfied that the engine is not to be blamed for it, gained nothing by it, and should suffer nothing in consequence of this curtailment of the time by less than 2·5 per cent. The coal charged to the engine, and reckoned as consumed, was nearly sufficient to complete the full five hours; yet credit was given only for the time actually run.

THE HUBER MANUFACTURING CO.'S ENGINE.

This engine, designed by Mr. Huber, and built under his superintendence, is noticeable for many peculiarities and much originality and boldness. It would be indeed remarkable if all the innovations upon approved practice here combined were real improvements, but one or more of them seem to me to be worthy of study, of trial, perhaps of general adoption. In general appearance the whole machine is "chubby," clumsy, and unprepossessing, and it certainly should have been better constructed; but, with all its shortcomings, both of detail and performance, it is rare that so much efficiency has been obtained from so small an amount of material,

both in bulk and weight, as will be found in this engine. It is very short, only about six feet over all, save the narrow foot-board, so that its wheels, all small, are brought close together. Very short in the water space, only 4 ft., 6 in., and 3 ft. in diameter, with a dome 16 in. diameter nearly in the middle of its length; grades, ascending or descending, are of little consequence to it as affecting its water level. The engine is vertical on the "off" or right hand side, partly covered by the driving wheel. Its factor of traction, obtained by multiplying together the number of cubic feet in the volume swept through by the piston per revolution, and the number of revolutions of the engine shaft per mile run, without slip; and dividing this product by the weight of the engine in running order (see line 280, Table I.) is very large, ·258—32 per cent. larger than in the Frick engine (·196), and 47 per cent. larger than in the Geiser engine (·176). This, in connection with the lighter load it drew over the hard places, and an arrangement to be explained for connecting the drivers, will explain its apparently remarkable performance at Tower Hill on the field trial. Its supplementary feed-water heater around the smoke-box, together with its capacious water tank carried ahead of its enlarged smoke-box, gives it a top-heavy appearance, and this considerable weight so far forward on an engine with so short a wheel-base, must diminish the adhesion of the drivers on level ground, while rather assisting it on steep ascents.

The simple and effectual method of coupling together the two drivers, rendering the equalizing gear for the time inoperative, and compelling each driving wheel to help the other, proved its utility at Tower Hill, and will be again referred to.

Carrying the steam pipe down through a sleeve in the steam and water space, through the fire-box in its hottest part, and through another sleeve in the lower water space, may help to give dry steam, and did, I think, prove itself useful in that way, but might be considered hazardous with a hot fire and steam current all shut off, even at the lower end, since the steam confined in this pipe might become intensely superheated, communicating with the steam space of the boiler, as it does at the top of the dome, through the governor throttle. The most meritorious novelty is the link-reversing motion. A short hand-wheel shaft carries on its forward end a beveled pinion, arranged to slide on a "feather" or spline in the shaft. This beveled pinion engages with a beveled segment on the side of a shifting link, and by turning the hand wheel the link is raised or lowered—reversing the engine or varying the cut-off, at pleasure. The axis of this pinion being exactly on a level with the center of the

valve stem, the link block has no sliding motion, no "slip," and consequently little wear.

On the other hand, the pinion slides backward and forward at every stroke of the engine. How far the wear these parts must suffer may counter-balance the saving of wear at the link block can only be ascertained by experience.

Trial of the Huber Engine. The start was late—5 h., 26 m., 50 s., P. M.—about dark, and one of our best observers, Prof. Warder, was otherwise engaged. No friction cards were taken, as that would have delayed the start till nearly seven o'clock. No exact measurement of the circumference of the 32 in. pulley (so-called) was taken, and taking this as the diameter at the edge, the computed circumference, 108·8 in., gives a slip of belt equal to 2·6 per cent. In the previous cases it was 0·9 to 1·0 per cent., and the circumference of Mr. Huber's pulley may have varied slightly from the estimate. Too much was attempted. The same load on the brake, 77·5 lbs., which, with 248·54 revolutions of the brake shaft per minute, gave the Frick engine 19·26 D. H. P., and which, with 277·71 revolutions per minute, gave the Geiser engine 21·52 D. H. P., gave the Huber engine only 16·63 D. H. P., with 214·64 revolutions of the brake shaft, and 273·52 revolutions of the engine shaft per minute. This, it is true, was about the same loss in proportion to the volume swept through by the respective pistons, per revolution, on either of the others; but in view of its very restricted heating surface it was excessive. To carry this heavy load, 16·63 D. H. P., 18·84 I. H. P., with an engine having only 7 in. cylinder diameter and 8 in. stroke, with no more than 364·71 ft. per minute piston speed, required of course, a high mean effective pressure; and to generate steam to maintain this pressure with a boiler having only 71·55 sq. ft. of heating surface, counting the whole surface of the supplementary heater around the smoke-box, of course required a small blast-pipe.

Mr. Huber also thought it advisable to so set the throttle valve of his Waters' governor that it could not much reduce the pressure at any speed attained, and therefore held in reserve little power, if any, to meet a sudden augmentation of resistance. In consequence of this attempt to run without reserved pressure, "from hand to mouth," in connection with the variations of resistance of which I have spoken at length in the account of the trial of the Geiser engine, this Huber engine stopped no less than six times, including the final stop at 10 h., 30 m., 40 s., which was a few minutes earlier than I intended to close the trial, but too near

the end to be worth while to start again. The following abstract of the time-log will give an idea of the unexpectedness of these stops:

	Running Time.	Stops.
First run	1. 5. 40	
First stop		0. 1. 40
Second run	0. 0. 35	
Second stop		0. 1. 55
Third run	0. 43. 25	
Third stop		0. 2. 30
Fourth run	1. 20. 20	
Fourth stop		0. 1. 15
Fifth run	0. 0. 30	
Fifth stop		0. 0. 20
Sixth run	1. 46. 20	
Totals	4. 56. 50	0. 7. 40

Running time		4. 56. 50
Time, beginning to end of trial		5. 4. 30
10. 30. 40	Trial ended.	
5. 26. 10	Trial begun.	
5. 4. 30	Length of trial.	

Steam pressure was very well maintained, and was never low enough during the whole trial to account for stopping; indeed, the engine ran along smoothly at the lowest recorded pressures, and at some of the stoppages the pressure was about at its highest.

The explanation I have already given in the case of the Geiser engine is, doubtless, the true explanation here.

Water level varied a good deal. It was occasionally quite at the top of the tube of the glass water gauge, and oftener almost at the bottom. The mean is very low (l. 124), and much of the time it must have left the upper row of 3-in. return flues partly uncovered. Hazardous as this may have been, it doubtless helped to give the extremely dry steam that was generally supplied to the cylinders, although there were instances not a few of priming, when the water was high, and when an overflow pipe from the heater was carrying a good deal of oil into the feed-water barrel. This last practice was discontinued early in the trial, and this overflow allowed to run to waste, which caused an unknown amount of loss.

It seems difficult to understand the small excess of water used over steam expended (ll. 141, 142) in view of this lost water, of the not

infrequent instances of excessivepriming, and of thehard work required of the boiler, without the assumption that the partly uncovered flues and the passage of the steam pipe through the fire may have given, during a large part of the time, unusually dry steam.

The diagrams do not call for much comment, as their character is stamped on their face. With a more judicious load, say 10 to 12 horse power, dynamic, with the link properly set in view of this lighter load, and with a blast-pipe nozzle 1⅛ in. or 1¼ in. diameter, which would have made sufficient draught, and would have caused much less back pressure, this engine might have ranged close up to the others in performance, and would certainly have performed its task without fault.

A word about draught, applicable to all the engines tested. A 12 in. pipe, with an elbow nearly a full right angle, but rounded to about one foot radius on the inner side, entered a chimney 12 in. square at about 19 ft. from the floor. It was intended to enter the chimney obliquely, but was carried in about at right angles, making a square turn at the chimney, which was about 45 ft. high from the floor on which the engines stood, say about 43 ft. high above the grates. This chimney certainly did not aid the draught, and sometimes obviously obstructed it.

It will be admitted, I think, that no possible manipulation of the data obtained at these economy tests could modify the relative rank I assign to the competing engines, with respect to economy or the result of the tests:

1. The Geiser Engine.
2. The Frick Engine.
3. The Huber Engine.

TABLE I.

DESCRIPTIONS, DIMENSIONS, AND DATA OF COMBINED TRACTION AND FARM ENGINES.

DIMENSIONS, QUANTITIES, AND DETAILS.	Kind of Quantity.	Huber.	Frick.	Geiser.
DESCRIPTION OF BOILER.				
1 Form of boiler		Cylind'r,	Locomotive.	Locomotive.
2 Fire-box bottom		Closed.	Closed.	Open.
3 Length of fire-box	inches,	54	32	36
4 Width of fire-box	inches,	Diam. 24	21.5	21.
5 Height of fire-box above grates	inches,	15	24.	28.
6 Diameter of waist	inches,	36.	28.	26.
7 Height, crown sheet to roof sh't, back end.	inches,	10	10	12
8 Height, crown sh't to roof sh't, front end.	inches,	10	13.25	10
9 Length of fire-grates	inches,	30	32	36
10 Width of fire-grates	inches,	22	21.5	21
11 Fire-grate area	sq. ft.,	4.38	4.78	5.25
12 Ratio of openings to fire-grate area		.30	.23	.40
13 Number of flues		12	46.	33.
14 Diameter of flues	inches,	3	2	2
15 Length of flues	inches,	54	69.5	60
16 Heating-surface; fire-box above grates	sq. ft.,	16.38	20.54	26.
17 Heating-surface; flues, outside	sq. ft.,	42.41	139.50	85.50
18 Smoke-box heating surface	sq. ft.,	11.76	2.	2.
19 Heating-surface, total	sq. ft.,	70.35	162.04	113.20
20 Super-heating surface, smoke-box	sq. ft.,	1.	1.	1.
21 Total heating and super-heating surface.	sq. ft.,	71.55	163.04	114.20
22 External radiating-surface	sq. ft.,	74.10	97.60	66.10
23 Ratio of radiating-surface to grates		17.	20.4	12.6
24 Ratio of radiat'g-surf'e to heat'g-surface.		1.05	.60	.58
25 Length of smoke-box	inches,	14	16.	15.
26 Draft area in flues	sq. ft.,	.30	.86	.63
27 Ratio of draft area to fire-grates		.07	.18	.12
28 Ratio of draft area to grate openings		.23	.78	.30
29 Ratio of heating-surface to grates		16.2	34.1	21.3
30 Diameter of smoke-pipe	inches,	7.	11.	8.
31 Ratio of smoke-pipe to draft area		.89	.77	.55
32 Location of dome		Middle,	Forward,	Forward.
33 Diameter of dome	inches,	16	18	14
34 Height of dome	inches,	14.5	18	14
35 Thickness of flue-sheets	inches,	.375	.375	.375
36 Thickness of fire-box plates	inches,	.31	.25	.25
37 Thickness of sides and roof, outside	inches,	Cylin'cal	.26	.34
38 Thickness of doors and throat-sheets	inches,	None,	.26	.31
39 Thickness of waist-sheet	inches,	.25	.31	.28
40 Riveting of longitudinal seams		Single,	Single,	Single.
41 Diameter of rivets	inches,	.625	.625	.625

TABLE I.—CONTINUED.

DIMENSIONS, QUANTITIES, AND DETAILS.	Kind of Quantity.	Huber.	Frick.	Geiser.
42 Pitch of rivets	inches,	1.875	2.000	1.875
43 Diameter of screw stay-bolts	inches,	None,	.81	.81
44 Spacing of screw stay-bolts, in crown	inches,	None,	4.5x5.	4.5x5.
45 Spacing of screw stay-bolts, in sides	inches,	None,	4.25x5.	4.5x5.
46 Form of fire-door		Rect'gle,	Round,	Rect'gle.
47 Width of fire-door	inches,	10	14	11
48 Height of fire-door	inches,	12	14	9
49 Number of mud-plugs or holes		6	2	2
50 Is there a foam-cock?		Yes,	No,	No.
51 Is there a steam-hose?		Yes,	No,	No.
52 Is there a foot-valve on suction?		Yes,	No,	No.
53 Is there a strainer on suction-hose?		Yes,	Yes,	Yes.
54 Is there a spark-arrester?		Yes,	Yes,	Yes.
55 Is there a fusible plug?		(?)	Yes,	Yes.
56 Isithere a variable exhaust?		Yes,	No,	Yes.
57 Diameter of blast-pipe, greatest	inches,	0.75	2.	2.
58 Width of water-space, door-end	inches,	None,	3.	2.25
59 Width of water-space, forward end	inches,	None,	3.	2.25
60 W dth of water-space, sides	inches,	Irregular	3.	2.25
61 Depth of water on crown-sheet; normal	inches,	6.	3.	3.
62 Water capacity at 80°, at 2.5 in. in g.w.g.	pounds,	734.	1058.	966.
63 Water capacity at 2.5 in. above bot. g.w.g.	c. ft.,	11.8	17.0	15.5
64 Steam capacity at 2.5″ in glass w. g	c. ft.,	4.3	12.9	8.8
65 Net area of water-surface at 2.5″ g.w.g.	sq. ft.,	9.3	18.1	17.1
DESCRIPTION OF ENGINE.				
66 Number of cylinders		One,	One,	One.
67 Position of cylinders		Vertical,	Horiz'tal	Horiz'tal
68 Location of cylinders, laterally		Side,	Center,	Side.
69 Location of cylinders, fore and aft		Aft,	Forward.	Forward.
70 Diameter of cylinder	inches,	7.	6.99	6.97
71 Length of stroke	inches,	8.	10.	10.
72 Area of cross-section of cylinder	sq. in.,	38.48	38.37	38.16
73 Diameter of piston-rod	inches,	1.125	1.187	1.125
74 Area of cross-section of piston-rod	sq. in.,	.99	1.11	.99
75 Area of small side of piston	sq. in.,	37.49	37.41	37.17
76 Vol. swept thro' by piston, forw'd stroke.	c. in.,	299.92	374.07	371.88
77 Vol. swept thro' by piston, forw'd stroke.	c. ft.,	.1735648	.2164757	.2152083
78 Vol. swept thro' by piston, return stroke.	c. in.,	307.84	383.75	381.55
79 Vol. swept thro' by piston, return stroke.	c. ft.,	.1781481	.2220775	.2208044
80 Vol. swept thro' by piston, mean, per rev.	c. in.,	607.76	757.82	753.43
81 Vol. swept thro' by piston, mean, per rev.	c. ft.,	.3517129	.4385532	.4360127
82 Length of clearance, end nearest to crank.	stroke,	.09	.1018	.0775
83 L'gth of clearance, end furthest from cr'k.	stroke,	.0924	.1218	.0625
84 Mean length of clearance in turns of cr'k.	stroke,	.0912	.1118	.07

TABLE I.—CONTINUED.

	DIMENSIONS, QUANTITIES, AND DETAILS.	Kind of Quantity.	Huber.	Frick.	Geiser.
	PERFORMANCE OF ENGINE AT TRIAL.				
85	Rev. per minute, mean, during trial......	rev. per m.,	273.53	221.65	231.65
86	Velocity of piston, feet per minute, mean.	ft. per m.,	364.71	369.42	386.08
87	Mean effective pressure during trial......	lbs. per sq. in.,	44.86	50.29	54.96
88	Mean pressure by steam gauge on boiler.	lbs. per sq. in.,	107.04	112.6	113.7
89	Mean pressure by standard gauge.........	lbs. per sq. in.,	102.6	106.7	109.8
90	Mean initial pres. in cyl., forward stroke.	lbs. per sq. in.,	73.8	82.2	83.5
91	Mean pressure at actual cut-off............	lbs. per sq. in.,	59.7	61.0	62.9
92	Mean pressure at exhaust, at .95 stroke..	lbs. per sq. in.,	42.	33.4	32.8
93	Mean absolute boiler pressure..............	lbs. per sq. in.,	117.3	121.4	124.5
94	Mean absolute initial p., forward stroke.	lbs. per sq. in.,	88.7	93.4	102.2
95	Mean absolute initial p., return stroke...	lbs. per sq. in.,	88.3	100.4	94.2
96	Mean absolute initial p., both strokes....	lbs. per sq. in.	88.5	96.9	98.2
97	Mean abs. p. at cut-off, forward stroke...	lbs. per sq. in.,	71.9	75.1	84.0
98	Mean abs. p. at cut-off, return stroke.....	lbs. per sq. in..	76.9	76.3	71.2
99	Mean abs. p. at cut-off, both strokes......	lbs. per sq. in.,	74.4	75.7	77.6
100	Mean abs. p. at exhaust, 0.95, for. stroke.	lbs. per sq. in.,	51.7	39.8	48.9
101	Mean abs. p. at exhaust, return stroke...	lbs. per sq. in..	61.7	56.4	46.1
102	Mean abs. p. at exh'st, 0.95, both strokes.	lbs. per sq. in..	56.7	48.1	47.5
103	Mean abs. pres. during forward stroke	lbs per sq. in,	72.80	66.03	77.12
104	Mean abs. pres. during return stroke.....	lbs. per sq. in..	76.22	76.47	70.80
105	Mean abs. pres. during both strokes......	lbs per sq in,	74.51	71.25	73.96
106	Mean abs. back p. and comp., for. stroke.	lbs. per sq. in..	28.9	17.72	19.20
107	Mean abs. back p. and comp., return str.	lbs. per sq in.	30.4	23.20	18.80
108	Mean abs. back p. & comp., both strokes.	lbs. per sq in..	29.65	20.96	19.00
109	Mean effective pressure, forward stroke.	lbs. per sq. in.	43.9	47.31	57.92
110	Mean effective pressure, return stroke....	lbs. per sq. in.,	45.82	53.27	52.00
111	Mean effective pressure, both strokes.....	lbs. per sq. in.	44.86	50.29	54.96
112	Actual cut-off, forward stroke...............	parts of str.,	.65	.44	.51
113	Actual cut-off, return stroke................	parts of str..	.75	.68	.59
114	Actual cut-off, mean of both strokes......	parts of str.,	.70	.56	.55
115	Steam exhausted per hour, for. stroke....	pounds,	340.2	241.1	339.1
116	Steam exhausted per hour, return stroke.	pounds,	424.2	419.4	323.3
117	Steam exhausted per hour, both strokes.	pounds,	764.4	660.5	662.4
118	Power produced, forward strokes..........	I. H. P.,	9.095	9.90	12.92
119	Power produced, return strokes............	I. H. P.,	9.745	11.43	11.30
120	Power produced, both strokes..............	I. H. P.,	18.84	21.33	24.22
121	Steam exp'ded per I. H. P. per h'r, for.str.	pounds,	37.41	24.35	26.25
122	Steam exp'ded per I. H. P. per h'r, ret.str.	pounds,	43.53	36.69	28.52
123	St'm exp'ded per I. H. P. per h'r, both str's.	pounds,	40.47	30.52	27.38
124	Mean height of water above bot. g. w. g	inches,	1.46	7.3	4.35
125	Mean temperature of external air.........	degrees F.,	84°.76	85°.4	91°.9
126	Mean temperature of feed-water...........	degrees F.,	86°.63	78.20	85.46
127	Mean temperature of water from heater.	degrees F.,	Not tak'n	161.3	141.5

TABLE I.—CONTINUED.

DIMENSIONS, QUANTITIES, AND DETAILS.	Kind of Quantity.	Huber.	Frick.	Geiser.
128 Rev. of engine shaft during trial..........	number,	81192.	67040.	67768.
129 Time run during trial........................	hours,	4.9472	5.041	4.87
130 Time run during trial..............	minutes,	296.833	302.46	292.55
131 Rev. of dynamometer shaft during trial.	number,	63683.	75173.	81246.
132 Mean rev. of engine shaft per minute.....	rev. per m.,	273.53	221.64	231.65
133 Mean rev. of dynam. shaft per minute ...	rev. per m.,	214.64	248.54	277.71
134 Power given off to dynamometer...........	D. H. P.,	16.63	19.26	21.52
135 Power consumed in friction; diff..........	H. P.,	2.21	2.07	2.70
136 Ratio of friction to I. H. P..................		.1173	.0970	.1115
137 Total quantity of water used during trial.	pounds,	4375.	5155.	4140.
138 Water used per hour............	pounds,	884.3	1022.6	850.1
139 Water used per hour per I. H. P..........	pounds,	46.94	47.94	35.10
140 Water used per hour per D. H. P.........	pounds,	53.17	53.09	39.50
141 Excess of water used over steam...........	per hour, lbs. per H. P.	6.47	*17.42	7.72
142 Ratio of excess to steam used		.1594	*.5708	.2819
143 Total quantity of coal used during trial...	pounds,	705.5	805.	723.3
144 Total quantity of refuse......................	pounds,	72.5	87.	90.2
145 Total quantity of combustible used........	pounds,	633.	718.	633.1
146 Ratio of refuse to coal used..................		.1077	.1081	.1247
147 Water evaporated per pound of coal......	pounds,	6.20	6.40	5.72
148 Water evap'ted per lb. of combustibles...	pounds,	6.91	7.18	6.54
149 Evap. from and at 212°, per lb. of coal..	pounds,	7.82	8.08	7.22
150 Evap. from & at 212°, per lb. of combust'le.	pounds,	8.71	9.06	8.26
151 Evaporation per hour per sq. ft. of grate...	pounds,	201.9	213.9	167.6
152 Evap. per hour per sq. ft. of heat. surf...	pounds,	12.36	6.27	9.94
153 Coal burned per hour per sq. ft. of grate.	pounds,	32.8	33.4	28.3
154 Coal burned per hour...................... .	pounds,	142.56	159.69	148.51
155 Combustible burned per hour...............	pounds,	128.17	142.43	129.99
156 Coal burned per hour, per I. H. P........	pounds,	7.57	7.46	6.13
157 Coal burned per hour, per D. H. P.......	pounds,	8.57	8.29	6.90
158 Combustible per hour, per I. H. P........	pounds,	6.80	6.68	5.36
159 Combustible per hour, per D. H. P......	pounds,	7.71	7.39	6.04
160 Mean abs. temperature of boiler steam ..	deg. F.,	790°.6	793°.5	795°.6
161 Abs. temperature of steam at 14.7 lbs str.	deg. F.,	673°.2	673°.2	673°.2
162 Total range of temperature, t—t............	deg. F.,	117°.4	120°.3	122°.4
163 Theoretical efficiency, $\frac{t-t.}{t.}$..		.1485	.1516	.1538
164 Mean abstract initial t. in cylinder........	deg. F.,	779°.9	786°.5	787°.5
165 Mean abstract back p. temperature........	deg. F.,	708°.9	681°.9	680°.6
166 Range of temperature, t_2-t_3...............	deg. F.,	71°.0	104°.6	106°.9
167 Actual theoretical efficiency, $\frac{t_2-t_3}{t_3}$........		.0898	.1330	.1357
168 Value in feet lbs. of combustible burned.	ft. pounds,	73494400	72197440	57930880

*There was a good deal of steam lost from valve-stem stuffer. There is no reason to suppose that the ratio of entrance water was greater than in the other engines.

TABLE I.—CONTINUED.

DIMENSIONS, QUANTITIES, AND DETAILS.	Kind of *Quantity.	Huber.	Frick.	Geiser.
169 Value in feet lbs. of power prod., I. H. P.	ft. pounds,	1980000	1980000	1980000
170 Efficiency actually obt'ed, l. 169.÷l. 168		.0269	.0274	.0342
171 Ratio of act'l obt'ed to act'l theoretical E.		.3000	.2060	.2520
172 Ratio of act'l obt'ed to total theoretical E.		.1811	.1807	.2224
173 Rat. of total fill., incl. cl. to lgth. str., for. str.		.74	.5418	.5875
174 Rat. of total fill., incl. cl. to lgth. str., ret. str.		.8424	.8018	.6525
175 Rat. of tot. fill., incl. cl. to lgth. str., both str.		.7912	.6718	.6200
176 Ratio of expansion, forward stroke........		1.36	1.85	1.70
177 Ratio of expansion, return stroke..........		1.19	1.25	1.53
178 Ratio of expansion, both strokes...........		1 20	1.49	1.60
179 Efficiency of boiler and heater..............		.5569	.5828	.5207
180 Effic'cy of heater in terms of boiler effic'cy.		Not tak'n	.0737	.0493
GENERAL DESCRIPTION.				
181 Length of cross-head pin.....................	inches,	2.	1.875	1.5
182 Diameter of cross-head pin..................	inches.	1.375	1.25	1.25
183 Stile of slides....................................		Double,	Double,	Double.
184 Length of cross-head rear-plates...........	inches,	6.	7.	8.
185 Width of cross-head rear-plates............	inches,	2.5	2.25	3.
186 Length of connecting rod, c to c...........	inches,	21.	30.	31.
187 Length of con'ting rod in terms of crank.		5.25	6.	6.2
188 Length of crank-pin...........................	inches,	2.	2.625	2.
189 Diameter of crank pin........................	inches,	1.375	2.625	2.
190 Material of connecting-rod boxes..........		Brass,	Brass,	Brass.
191 Material of crank-shaft........................		Forged I	Forged I	F. Steel.
192 Diameter of crank-shaft.......................	inches,	2.25	2.625	2.75
193 Length of crank-shaft bearings............	inches,	6.	8.25	9.
194 Lining of crank-shaft boxes.................		Babbitt,	Br. & B't,	Babbitt.
195 Style of valve-gear.............................		Link,	Link,	Rev'sible Ecc'ntric
196 Style of valve....................................		Slide,	Slide,	Slide,
197 Length of ports..................................	inches,	4.5	6.	5.
198 Width of steam-ports..........................	inches,	.5	.75	.625
199 Width of exhaust-ports.......................	inches,	1.25	1.25	1.
200 Outside lap of valve...........................	inches,	(?)	.72	.625
201 Inside lap of valve..............................	inches,	.03	.06	.04
202 Greatest throw of valve.......................	inches,	1.75	2.25	2.25
203 Least throw of valve...........................	inches,	.19	.78	2.25
204 Can reverse-motion be used for exp'sion?		Yes,	Yes,	No.
205 Kind of governor................................		Waters,	Pick'ring	Pick'ring
206 Diameter of fly-wheel pulley................	inches,	32.	45.	48.
207 Width of belt-face of fly-wheel.............	inches,	7.	8.5	6.5
208 Weight of fly-wheel, estimated............	pounds,	200.	420.	480.
209 Diameter of steam-pipe.......................	inches,	1.25	1.5	1.5
210 L'gth of steam-pipe inside of steam-space.	inches,	48.	0.	0.
211 Length of steam-pipe outside of boiler...	inches,	24.	34.	30.

TABLE I.—CONTINUED.

DIMENSIONS, QUANTITIES, AND DETAILS.	Kind of Quantity.	Huber.	Frick.	Geiser.
212 Diameter of exhaust-pipe	inches,	1.25	2.	2.25
213 Length of feed-pipe in heater	inches,	108.	120.	78.
214 Diameter of feed-pipe in heater, inside	inches,	.75	.75	1.
215 Location of water-tank		Forward,	Aft,	Aft.
216 Capacity of water-tank	pounds,	844	1000.	675.
217 Capacity of coal-bunkers, estimated	pounds,	160.	200.	200.
218 Style of feed-pump, driven from c. head.		Full str.,	Full str.,	Full str.
219 Style of supplementary pump		None,	Up. st. p.,	Up. st. p.
220 Diameter of feed-pump piston	inches,	.75	.875	.855
221 Stroke of feed-pump piston	inches,	8.	10.	10.
DESCRIPTION OF RUNNING GEAR.				
222 Diameter of driving (grand) wheels	inches,	49.	60.	66.
223 Width of driving-wheel tire	inches,	8.	8.	8.
224 Material of rim; kind of iron	iron,	Cast,	Wrought	Wrought
225 Form of corrugations		Rectangular,	Oblique,	Oblique.
226 Material of spokes		Wrt. iron,	Wrt. iron,	Wood.
227 Number of spokes in each wheel	number,	20.	17.	14.
228 Form of spokes		Round,	Flat,	Square.
229 Dimensions of spokes	inches,	di., .625	2.x0.5	sq. 2.375
230 Mode of fastening spokes to rim		Cast i'n,	Riveted,	Tenon.
231 Material of hub, kind of iron	iron,	Cast,	Cast,	Cast.
232 Diameter of bearing in hub	inches,	2.875	12.	3.5
233 Diameter of bearing on axle	inches,	2.875	8.	4.
234 Mode of fastening spokes to hub		Cast i'n,	Cast i'n,	C't i'n c'p
235 Kind of riding-springs, aft	steel,	None,	Spiral,	Spiral.
236 Kind of riding.springs, forward	steel,	None,	Spiral,	Spiral.
237 Diameter of forward wheels	inches,	33.	42.	40.
238 Width of tread of forward wheels	inches,	4.	3.	3.
239 Material of rim of forward wheels		Cast i'n,	W.: w.i.t.	W.: w.i.t.
240 Width of steering-tire on fore-wheels	inches,	2.	None,	.875
241 Thickness of steering-tire on fore-wheels.	inches,	.625	None,	.875
242 Material of spokes of fore-wheels		Wrt. iron,	Wood,	Wood.
243 Number of spokes in each fore-wheel	number,	12	12	16
244 Dimensions of spokes in fore-wheels	inches,	di. 0.5	h. 2.5x1.5	2.x1.
245 Material of hubs of fore-wheels		Cast i'n,	Cast i'n,	Cast i'n,
246 Diameter of forward axle in hub	inches,	2.25	2.375	.2375
247 Length of bearing in fore-wheels	inches,	8.	10.5	9.
248 Kind of steering-gear		W. & ch's	W. & ch's	W. & ch's
249 Is there a pole to attach horses?		Yes,	Yes,	Yes.
250 Location of equalizing gears		D. Axle,	Pin. sh't,	D. Axle.
251 Kind of gearing in equalizing gears		Spur,	Beveled,	Spur.
252 Style of gearing from engine shaft		Spur,	Spur,	Spur.
253 Pitch of spur gears, main train	inches,	1.375	2.125	2.
254 Large gears of equalizing gear		Outside,	Outside,	Inside.

TABLE I.—Continued.

DIMENSIONS, QUANTITIES, AND DETAILS.	Kind of Quantity.	Huber.	Frick.	Geiser.
255 Number of teeth in gears on drivers.......	number,	64	58	69
256 Pitch diameter of gears on drivers.........	inches,	28.	39.25	44.15
257 Face of spur gears, main train..............	inches,	2.25	2.75	2.
258 Material of pinions, equalizing gear.......		Cast i'n,	Cast i'n,	steel.
259 Number of pinions, equalizing gear.......		2 pair,	4.	3 pair.
260 Face of equalizing gears and pinions......	inches,	1.375	2.25	2.
261 Number of teeth in pinions, equal. gears.	number,	13.	10.	11.
262 Pitch of equalizing gears	inches,	1.375	1.125	1.5
263 Pitch diam. pinions, equalizing gear......	inches,	6.	3.625	5.25
264 Number of teeth in gears, equalizing gear.	number,	32&36	30	62
265 Pitch diam. gears, equalizing gear.........	inches.	14.&16.	10.81	31.5
266 Number of teeth in pinion on pin. shaft.	number,	11	11	10
267 Pitch diam. of pinion on pinion shaft.....	inches,	5.25	7.5	6.38
268 Face of pinion on pinion shaft..............	inches,	3.	3.	4.
269 Number of teeth in pin. on engine shaft.	number,	13.	29.	11.
270 Pitch diameter of pinion on engine shaft.	inches,	6.	12.75	7.5
271 Face of pinion on engine shaft.............	inches,	2.25	2.25	2.5
272 Number of teeth in gear on pinion shaft.	number,	32.	96	31.
273 Pitch diameter of gear on pinion shaft...	inches,	14.	42.25	19.7
274 Face of gear on pinion shaft.................	inches,	2.25	2.25	2.
275 Number of rev. of eng. shaft to 1 of driv.		14.32	17.454	17.7
276 Number of rev. of eng. shaft per mile.....		5997.4	5866.5	5408.8
277 Number of rev. of driving-wheel per mile.		418.81	336.1	305.58
278 Vol. swept thro. by piston per mile run..	cub. ft.,	2109.	2573.	2358.
279 Weight of engine, with water and fuel...	pounds,	8175.	13100	13425.
280 Vol. per mile divided by pounds weight.	factor,	.258	.196	.176
SUMMARY OF LOG, FIELD TRIAL.				
281 Equated time of starting; crossing Green Street.........		12.10.23	10.10.46	12.10.0
282 Time of reaching Exposition building on return.........		5.34.0	4.50.0	4.43.50
283 Whole time occupied by run, including stops............		5.23.37	4.39.14	4.33.50
284 Time lost, by order of Judge, at Tower Hill, before asc't.		1.28.30	0.42.0	0.0.0
285 Time lost, by order of Judge, at Tower Hill, after asc't.		4.13	0.18.4	1.42.27
286 Time lost by Huber going around park, by mistake...		4.30		
287 Tot. lost time by order of Judge and by extra dis. run.		1.37.13	1.0.4	1.42.27
288 Actual running time, including all accidental stops....		3.46.24	3.39.10	2.51.23
289 Weight on drivers, with water and fuel..	pounds,	4750.	10000.	10375.
290 Weight on fore-wheels, with water & fuel.	pounds,	3425	3100.	3050
291 Total weight of engine in running order.	pounds,	8175	13100.	13425.
292 Weight of water & fuel included in total	pounds,	1162	2446	1788
293 Total net weight of engines..................	pounds,	7013	10654	11637
294 Water used during the run	pounds,	1894.	2875.	2339.

TABLE I.—CONTINUED.

DIMENSIONS, QUANTITIES, AND DETAILS.	Kind of Quantity.	Huber.	Frick.	Geiser.
295 Rate of evaporation at economy trial......		6.2	6.4	5.72
296 Coal used at same rate as in eco'my trial.	pounds,	305.	449.	409.
297 Total load at starting........................	pounds,	3450.	7830.	8440.
298 Load carried up Tower Hill.................	pounds,	2350.	6168.	3181.
299 Load brought back to Exposition build.	pounds,	1251	4506.	6217.
300 Estimated mean load during whole run...	pounds,	2350	5337.	5255.
301 Water used per 2000 pounds mean load..	pounds,	1612	1073	890.
302 Water used per 2000 pounds of engine...	pounds,	463	439	348
303 Water used per 2000 lbs., engine & load.	pounds,	402	305	250
RATE OF EVAPORATION, ETC.				
304 Mean pressure by standard gauge, l. 89..	lbs. per sq. in.	102.6	106.7	109.8
305 Mean absolute pressure: Atm. = 14.7...	lbs. per sq. in.	117.3	121.4	124.5
306 Weight per cubic foot of steam of mean p.	pounds,	.26877	.27708	.28327
307 Weight per cubic inch of steam of mean p.	pounds,	00015554	00016035	00016393
308 Pounds of steam expended per h'r, l. 117.	pounds,	764.4	660.5	662.4
309 Pounds of steam expended per minute...	pounds,	12.74	11.008	11.04
310 Pounds of steam expended per second...	pounds,	.2123	.1835	.1840
311 Mean h'g't of w't'r in glass wat.ga'ge, l. 124	inches,	1.46	7.3	4.35
312 Area of water surface at mean height....	sq. ft.,	10.4	13.9	15.4
313 Vol. of steam exp'ed per sec., l. 310 ÷ l. 307	c. in. per sec.,	1365.	1144.	1122.
314 Vol. of steam in cub. in. per sq. ft., per sec.	cub. in., sec.,	131.	82.	73.

INDICATOR DIAGRAMS.

No. 1. Mean diagram taken from the Huber engine during the economy test, September 30, 1881, at 9 h., 8 m. P. M. Cut-off differs too much at the two ends, and is too late at both ends.

The excessive back pressure is due to the small blast-pipe nozzle—0·75 in. See lines 121, 122, 123, of preceding table. See page 79.

No. 2. Mean diagram from the Frick engine, taken during the trial, September 28, 1881, at 3 h., 30 m. P. M. The card from the end of the cylinder nearest crank, descending to the left hand, is very good for a throttling engine; and with a little less clearance, and a little more compression, would be excellent. As it is, it gives the best results of any single-end card taken during the trials. Had the other end been as good, relatively, this engine would have stood at the head in the economy trials. The effect of late release in causing excessive back-pressure is seen on this card. See lines 121, 122, 123, of foregoing table. See page 80.

No. 3. Mean diagram from the Geiser engine, taken during the trial, September 29, 1881, at 8 h., 7 m. P. M. Both these cards are remarkably good. Clearance 7·25 per cent. at crank end, and 6·25 per cent. at the out end—a mean of 7 per cent. Exhaust closure is about alike at the ends, but compression is a little less complete in the forward stroke, on account of the greater length of clearance at that end. This card actually contained five full lines, taken at intervals of three seconds—pretty evenly shading the spaces between the lines drawn in ink and engraved. It was selected from cards representing 172 full lines from each end of cylinder, because it almost exactly corresponded to the mean of all. The full, normal lines truly represent such mean.

Admission is a little late on return stroke, probably on account of the nice equalization of the other events Both admission and cut-off should be a little earlier at this end, and earlier release, and even earlier exhaust-closure would do no harm. A study of these cards, and of lines 121, 122 and 123 of table, will reveal the cause of every good and bad result of the various valve-adjustments at each end of these three cylinders—practically, six engines, so far as the use of steam is concerned. See page 81.

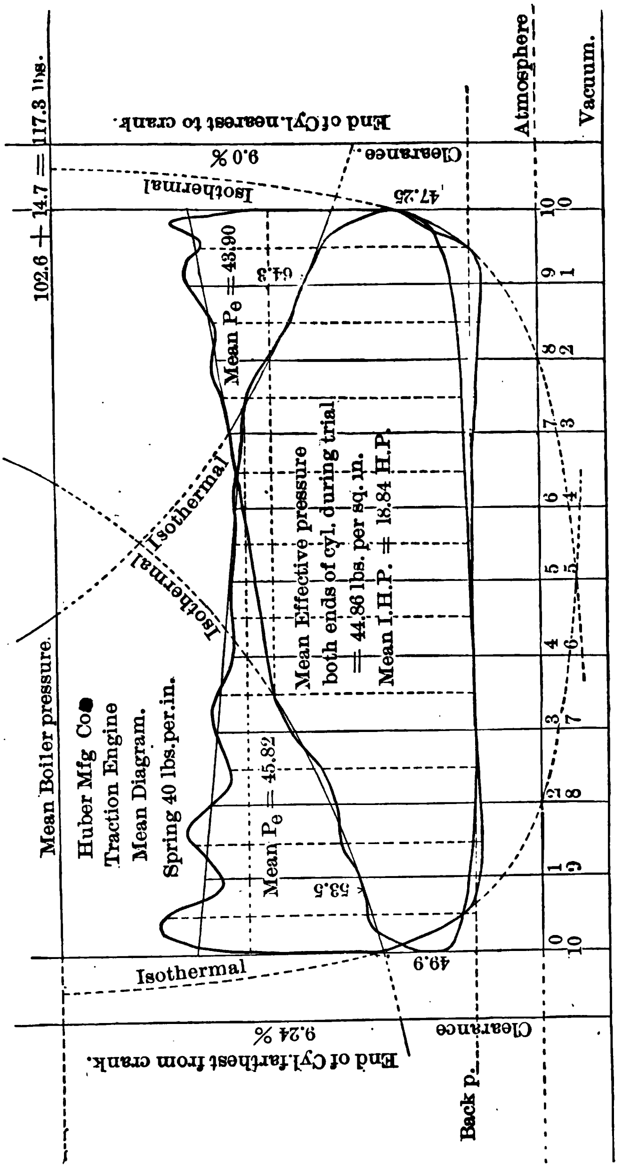

102.6 + 14.7 = 117.3 lbs.
End of Cyl. nearest to crank.
9.0 %
Clearance
Isothermal
47.25
Mean P_e = 43.90
64.8
Atmosphere
Vacuum.
Isothermal
Isothermal
Mean Effective pressure
both ends of cyl. during trial
= 44.86 lbs. per sq. in.
Mean I.H.P. = 18.84 H.P.
Mean Boiler pressure.
Huber Mfg Co.
Traction Engine
Mean Diagram.
Spring 40 lbs. per. in.
Mean P_e = 45.82
53.5
Isothermal
49.9
9.24 %
End of Cyl. farthest from crank.
Clearance
Back p.

Diagram No. 1.

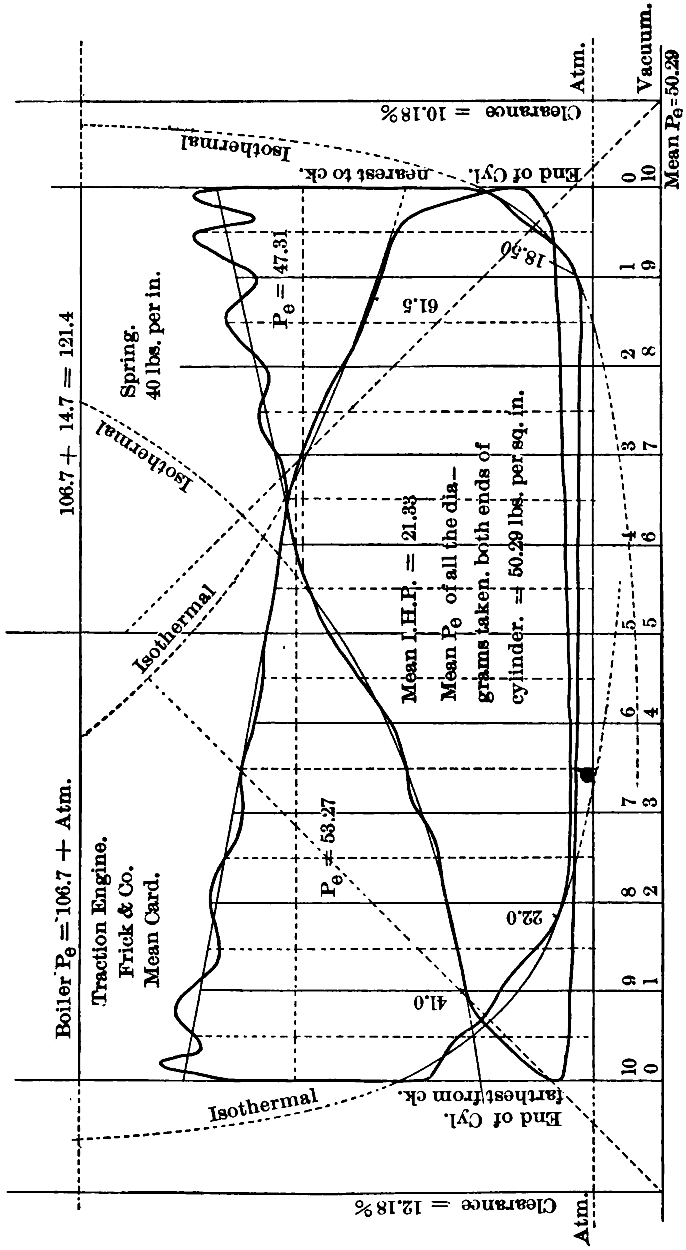

Boiler P_e = 106.7 + Atm.
106.7 + 14.7 = 121.4
Traction Engine.
Frick & Co.
Mean Card.
Spring.
40 lbs. per in.
Mean I.H.P. = 21.33
Mean P_e of all the diagrams taken, both ends of cylinder. = 50.29 lbs. per sq. in.
P_e = 47.31
P_e = 53.27
Isothermal
Isothermal
Isothermal
Isothermal
End of Cyl. nearest to ck.
End of Cyl. farthest from ck.
Clearance = 10.18%
Clearance = 12.18%
61.5
18.60
22.0
41.0
Atm.
Atm.
Vacuum.
Mean P_e=50.29

Diagram No. 2.

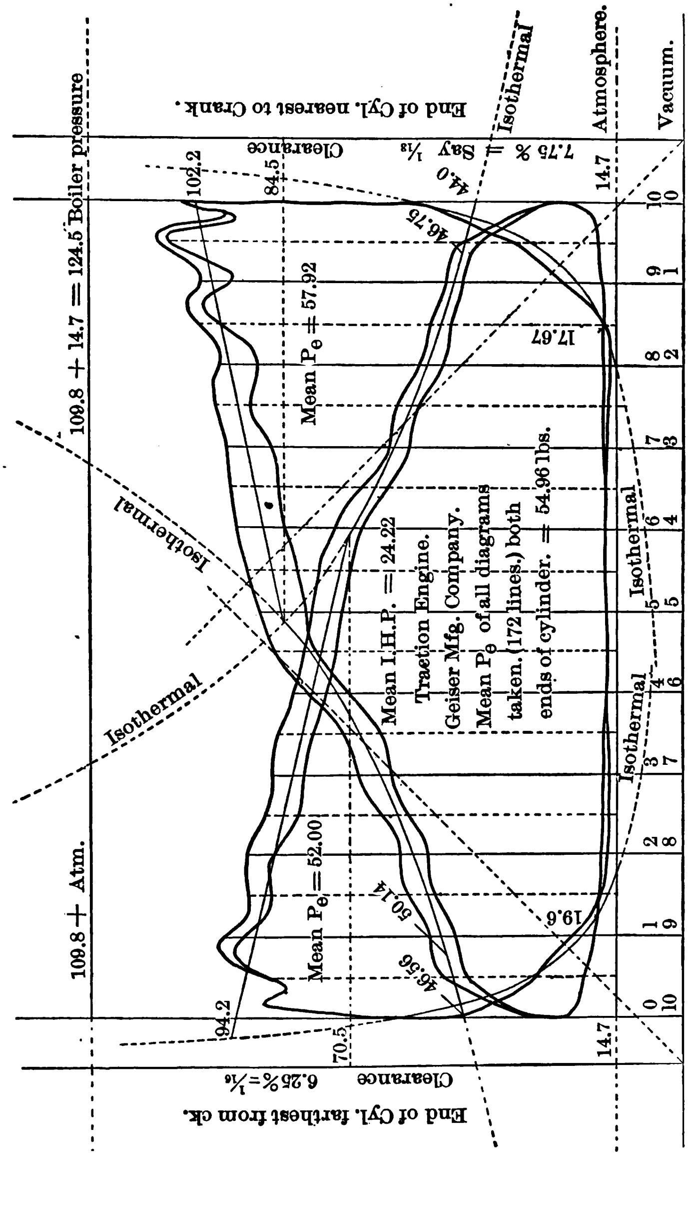

109.8 + 14.7 = 124.5 Boiler pressure
109.8 + Atm.
End of Cyl. nearest to Crank.
Clearance
7.75 % = Say 1/13
End of Cyl. farthest from ck.
Clearance 6.25% = 1/16
Atmosphere.
Vacuum.
Isothermal
Isothermal
Isothermal
Isothermal
Isothermal
102.2
84.5
44.0
46.75
17.67
14.7
94.2
70.5
50.14
19.6
46.56
14.7
Mean P_e = 57.92
Mean P_e = 52.00
Mean I.H.P. = 24.22
Traction Engine.
Geiser Mfg. Company.
Mean P_e of all diagrams
taken, (172 lines,) both
ends of cylinder. = 54.96 lbs.

Diagram No. 3.

PART SECOND.—FIELD TRIAL, OCTOBER 6, 1881.*

A detachment of mounted police, courteously furnished by the City Government, or Mayor, served to keep intrusive curiosity at just sufficient distance, and guarded against danger of frightening horses, and proved very useful.

The day was all that could be desired. Recent rains had laid the dust, and had so softened the ground in some parts of the route as to task the tractive qualities of the engines to the utmost. The air was cool, and there was a gentle breeze.

The Load. Each engine was required to draw, besides a full supply of water and fuel, at least 3,500† pounds, equal to the weight of a 42-in. separator, the arrangement of this load being left to the discretion of each exhibitor, as well as the actual load which each might undertake to draw.

Mr. Landis took from the Exposition building, as a load for the Geiser Manufacturing Company's engine:

Tender wagon, with water and coal, at start	4,200 lbs.
Passenger wagon, with 16 men, including firemen and observers, who in fact rode on the engine	4,100 lbs.
One man, not weighed with wagon	140 lbs.
Total	8,440 lbs.

The load which he brought back was:

Wagon, with coal and water	2,137 lbs.
Wagon, 15 men	3,940 lbs.
The one man before weighed	140 lbs.
Total	6,217 lbs.

But a part of this load was detached, as we shall see, on ascending Tower Hill. This engine also took two barrels of water on the way, weighing, net, 734 pounds.

Mr. Frick procured a city watering wagon, weighing, with its contents, at starting, 7,830 pounds, and at the end of the run, 5,035 lbs. This load was never detached, save when the engine slipped into a deep mud-

*A table is appended to this paper, showing the grades at the different parts of the route, and compiled from a Profile Map that appears in the Exposition Report.—EDS.

† The load brought back to the Exposition building was of little consequence, as it was drawn, mostly, down hill. It was the load drawn up Vine Street Hill, Tower Hill, and a few other places, that really tested the engines.—J. C. H.

hole, at 3 h., 31 m. P. M., and the wagon was then drawn out by a rope by the engine, and connected again in a few minutes.

Mr. Huber started from the Exposition building with a passenger wagon, containing a number of men in addition to his tender wagon, with water and coal; but, as he was obliged to detach this passenger wagon at 12 h., 30 m., before ascending Vine Street Hill, no account is here taken of it. His tender wagon, with water and coal, weighed, at starting, 3,450 lbs., and at the end of run, 1,251 lbs. See lines 297, 298, 299, Table I.

The Start. The time set for starting was 10 A. M., but numerous causes delayed it until noon. Steam having been raised, the fires were all drawn, and 4 lbs. of shavings and 20 lbs. of kindling wood were furnished to each engine. By a misapprehension of the order, upon the signal for starting fires, the Geiser engine started on the race, but was halted to wait for the arrival of the rest at Green Street, where the true start was made at 12 h., 10 m., 0 s., P. M. Two observers accompanied each engine, one instructed to record all that concerned the steam engine, the other to pay particular attention to the scale of the road and the performance of the running-gear. Mr. Walter Laidlaw accompanied me in a carriage, and we were able, for a considerable part of the way, to take pretty full notes of the working of at least two of the engines, and sometimes of all three. At Tower Hill, where the most severe test of their powers was applied, each engine made the ascent and descent separately, so that all were fully noted.

Water Used. The quantity of water used was satisfactorily ascertained, save the doubt that attaches to the suspiciously round numbers given by the city scales, on which the weighing was done. There is no other reason to doubt its accuracy. Not so with the coal. Although very accurately weighed to start with, an unknown quantity was lost off from two of the engines, and in one case the fire, drawn from the fire-box at the end of the run, was not weighed.

No way remained, therefore, but to take the rate of evaporation that had been found at the economy trial and apply it to the quantity of water used in the field trial. In the one case, in which the quantity of coal used was determined, the agreement with the evaporation at the economy trial was very close, and it is to be presumed that an almost equally close agreement would have been obtained if the quantity of coal burned had been known.

The coal was the same as before, best Youghiogheny.

INDICATOR DIAGRAMS.

The indicators used were a pair of Thompson indicators, made by the American Steam Gauge Company, Boston. One of them had been used at a high speed during the Exposition, and its barrel-spring had been tightened for that purpose. The fact that the other one had not been tightened was overlooked, so that this indicator, which by chance was placed on the Frick engine, could only be used at low speeds. The diagrams obtained show exactly the same characteristics as those from the same engine at the economy trial, already commented on. The other indicator was placed on the Geiser, and gave some interesting diagrams, which will be briefly noticed later. No diagrams could be taken from the Huber engine while running on the road, on account of the location of its cylinder partly behind the driving wheel.

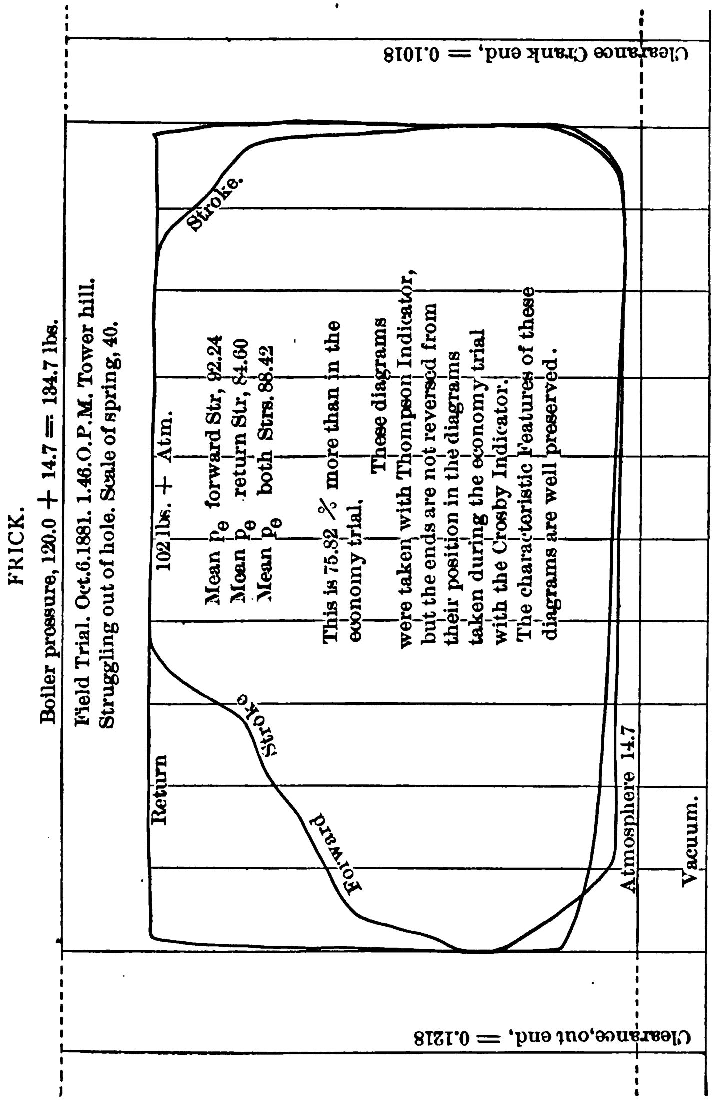

FRICK.
Boiler pressure, 120.0 + 14.7 = 134.7 lbs.
Field Trial. Oct.6.1881. 1.46.O.P.M. Tower hill.
Struggling out of hole. Scale of spring, 40.
Clearance Crank end, = 0.1018
Stroke.
102 lbs. + Atm.
Mean p_e forward Str, 92.24
Mean p_e return Str, 84.60
Mean p_e both Strs. 88.42
This is 75.82 % more than in the economy trial.
These diagrams were taken with Thompson Indicator, but the ends are not reversed from their position in the diagrams taken during the economy trial with the Crosby Indicator.
The characteristic features of these diagrams are well preserved.
Return
Stroke
Forward
Atmosphere 14.7
Vacuum.
Clearance,out end, = 0.1218

Diagram No. 4.

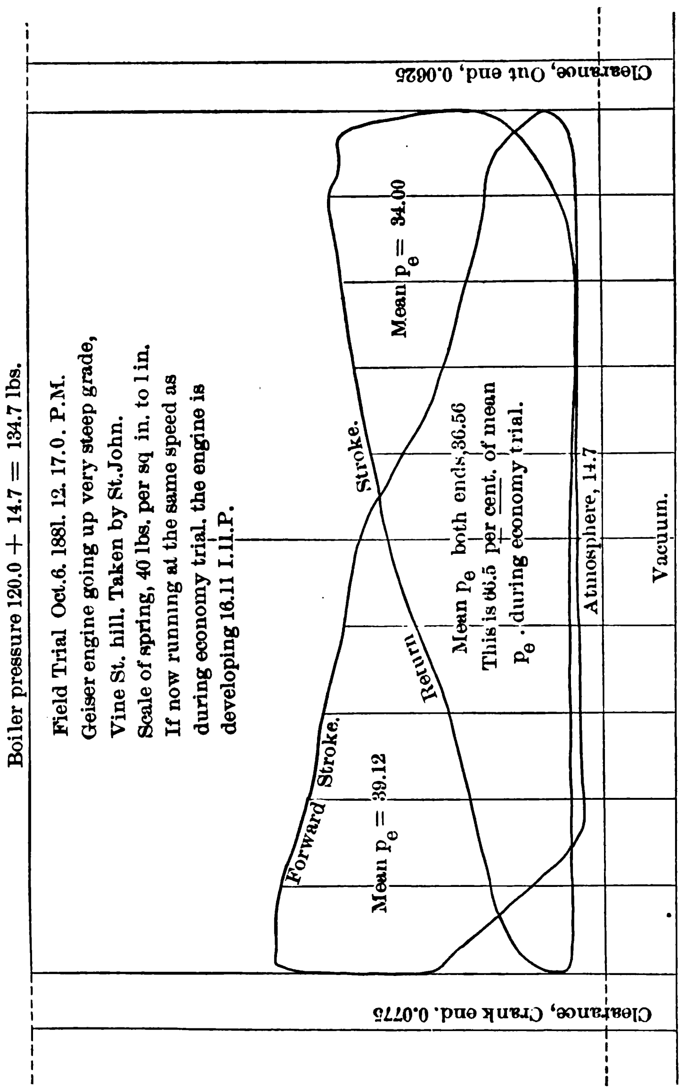

Boiler pressure 120.0 + 14.7 = 134.7 lbs.
Field Trial Oct.6. 1881. 12. 17.0. P.M.
Geiser engine going up very steep grade,
Vine St. hill. Taken by St.John.
Scale of spring, 40 lbs. per sq. in. to 1 in.
If now running at the same speed as
during economy trial. the engine is
developing 16.11 I.H.P.
Clearance, Out end, 0.0625
Mean p_e = 34.00
Forward Stroke.
Mean p_e = 39.12
Return Stroke.
Mean p_e both ends, 36.56
This is 66.5 per cent. of mean
p_e during economy trial.
Atmosphere, 14.7
Vacuum.
Clearance, Crank end, 0.0775

Diagram No. 5.

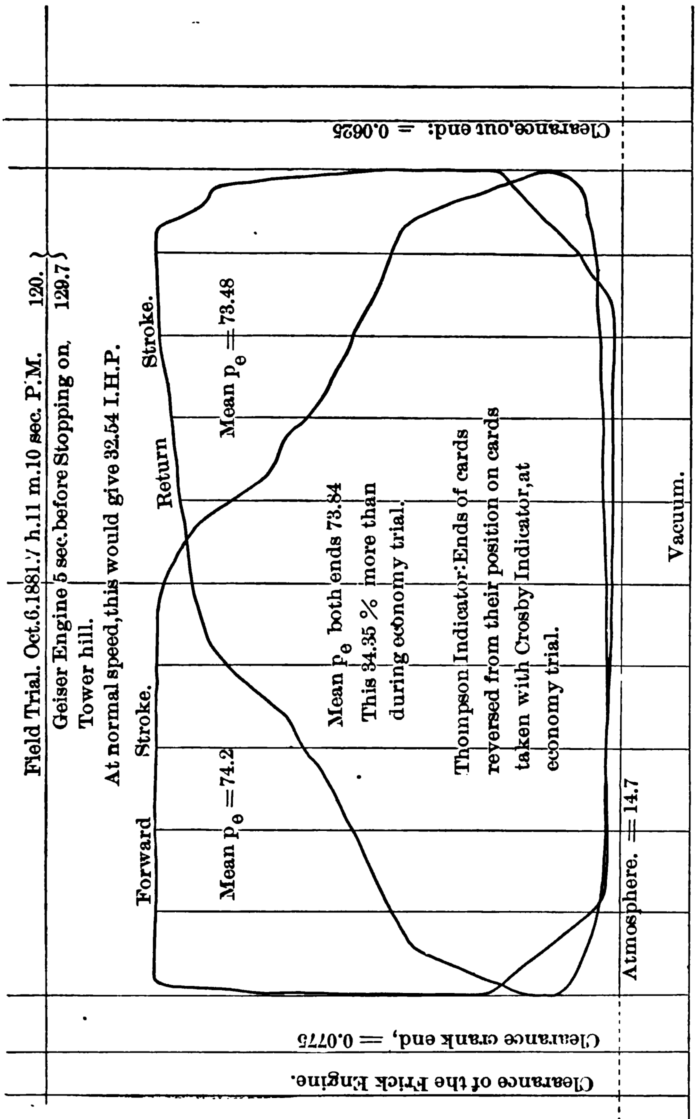

Field Trial. Oct.6.1881. 7 h.11 m.10 sec. P.M. 120.
Geiser Engine 5 sec.before Stopping on, 129.7
Tower hill.
At normal speed,this would give 32.54 I.H.P.
Forward Stroke.
Return Stroke.
Mean p_e = 74.2
Mean p_e = 73.48
Mean p_e both ends 73.84
This 34.35 % more than during economy trial.
Thompson Indicator:Ends of cards reversed from their position on cards taken with Crosby Indicator,at economy trial.
Atmosphere. = 14.7
Vacuum.
Clearance,out end: = 0.0625
Clearance crank end, = 0.0775
Clearance of the Frick Engine.

Diagram No. 6.

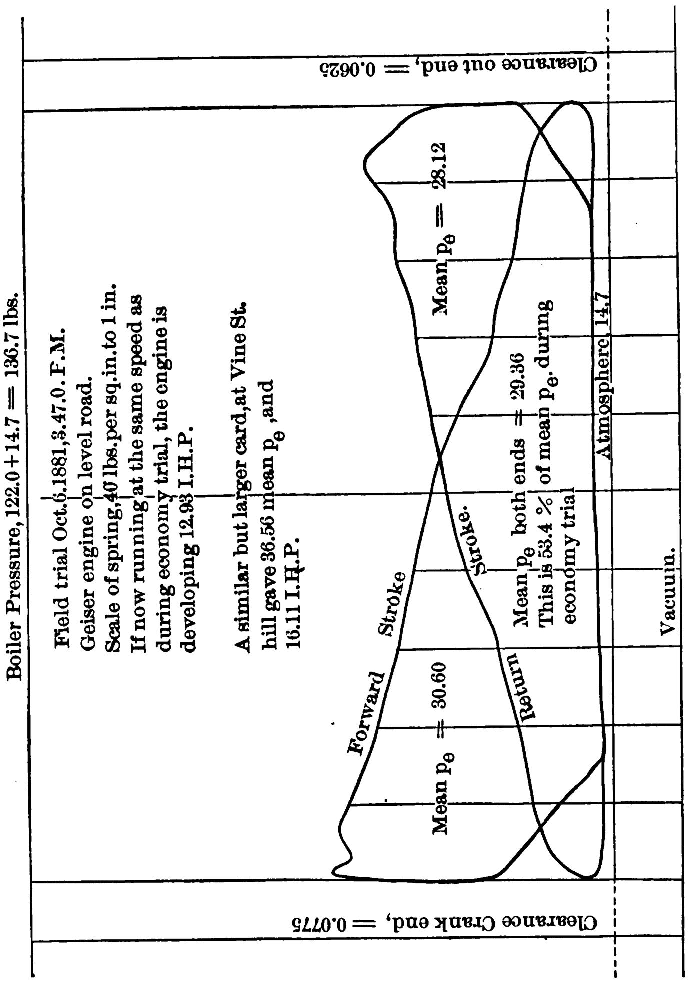

Boiler Pressure, 122.0 + 14.7 = 136.7 lbs.
Field trial Oct. 6.1881, 3.47.0. P.M.
Geiser engine on level road.
Scale of spring, 40 lbs. per sq. in. to 1 in.
If now running at the same speed as
during economy trial, the engine is
developing 12.93 I.H.P.
A similar but larger card, at Vine St.
hill gave 36.56 mean p_e, and
16.11 I.H.P.
Mean p_e = 28.12
Mean p_e = 30.60
Forward Stroke
Return Stroke.
Mean p_e both ends = 29.36
This is 53.4 % of mean p_e. during
economy trial
Atmosphere 14.7
Vacuum.
Clearance out end, = 0.0625
Clearance Crank end, = 0.0775

Diagram No. 7.

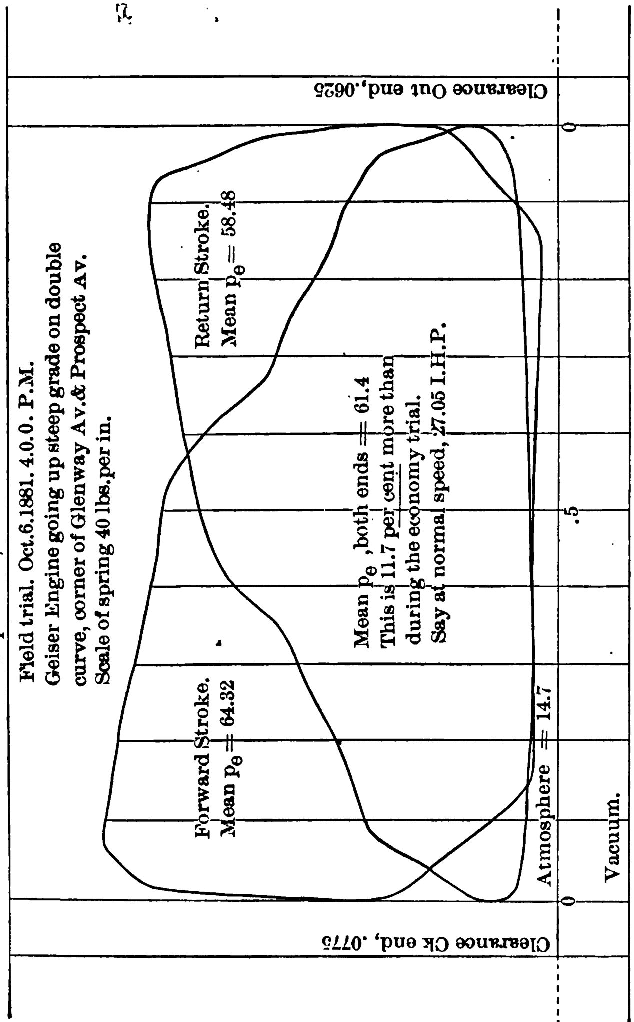

Boiler pressure,115.0 + 14.7 = 129.7 lbs.
Field trial. Oct.6.1881. 4.0.0. P.M.
Geiser Engine going up steep grade on double curve, corner of Glenway Av.& Prospect Av.
Scale of spring 40 lbs.per in.
Clearance Out end, .0625
Return Stroke.
Mean pe = 58.48
Mean pe, both ends = 61.4
This is 11.7 per cent more than during the economy trial.
Say at normal speed, 27.05 I.H.P.
Forward Stroke.
Mean pe = 64.32
Atmosphere = 14.7
Vacuum.
Clearance Ck end, .0775
0
.5
0

Diagram No. 8.

GEISER.

Boiler pressure, 108.0 + 14.7 = 122.7 lbs.

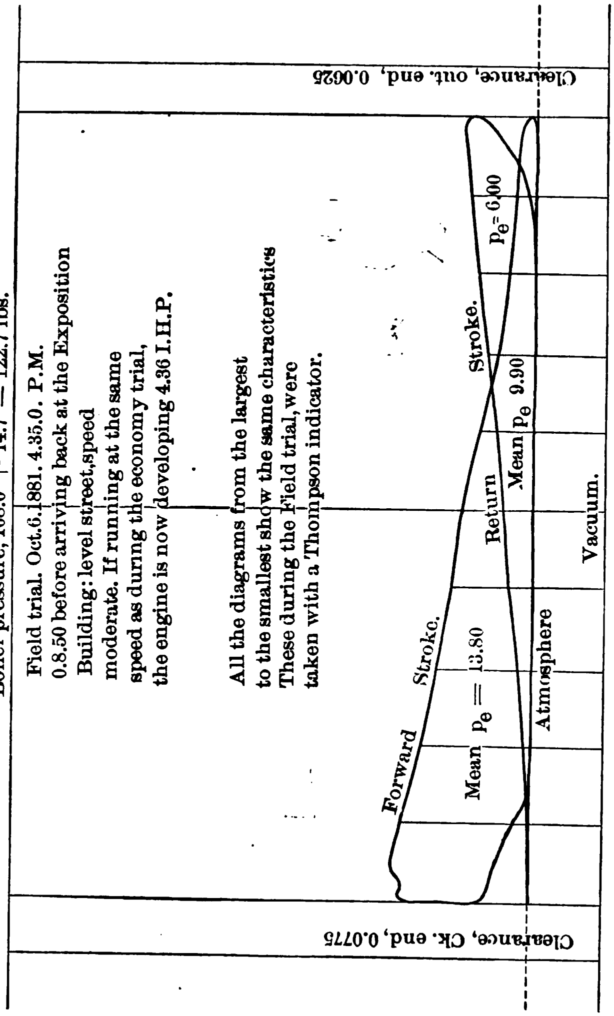


Diagram No. 9.

TABLE II., FIELD TRIAL OF COMBINED TRACTION AND FARM ENGINES.

Condensed Log, from the Notes of all the Observers.

Time of the events noted in margin at the right hand, with relation to the several engines named below; arranged in the order of starting.									NOTES AND REMARKS.
GEISER ENG.			HUBER ENG.			FRICK ENG.			
H.	M.	S.	H.	M.	S.	H.	M.	S.	
11	49	0	11	49	0	11	49	0	Fire set to kindlings; Geiser starts, the others soon follow.
12	10	0	12	10	0	12	10	0	True start, at a signal; Geiser at Green St., the others at intervals of 100 ft.
12	10	0	12	10	23	12	10	46	Equated time of starting, when each crosses Green St.
...	...	...	12	11	0	...	...	...	Huber stops; worm-gear of steering-apparatus loose, pin out.
...	...	...	12	11	35	...	...	...	Huber starts from near Green St., about 200 ft. behind Frick.
...	...	...	...	...	...	12	14	30	Frick at Findlay St.
12	15	0	12	15	0	12	15	0	Vine St. Hill; Geiser ahead, Frick second, Huber third.
...	...	...	12	18	0	...	...	...	Huber gets stalled at Vine St.
12	19	0	...	...	...	...	...	...	Geiser on Clifton Ave., corner of Ohio St., leaving Frick behind.
12	20	30	..	...	...	...	...	...	Geiser opposite McMicken University; goes finely up steep grade.
12	21	40	...	...	...	...	...	...	Geiser turns angle, Clifton Ave.
...	...	...	12	22	0	...	...	...	Huber stops on an iron casting, and backs.
12	22	15	...	...	...	...	...	...	Geiser almost stops for a frightened horse; starts nicely on very steep grade.
...	...	...	...	...	..	12	23	0	Frick at angle in Clifton Ave. 1 m., 20 sec. behind Geiser.
12	24	45	...	...	...	...	...	...	Geiser at Warner St.
...	...	...	12	27	0	...	...	...	Huber lost from 1 to 2 minutes waiting for horses.
12	27	0	...	...	...	...	...	...	Geiser at top of long hill; now descend.
...	...	...	12	30	0	...	...	...	Huber at Vine St. and Clifton Ave.; drivers slip on smooth crossing; wagon detached; engine still obliged to back before starting.
...	...	...	...	...	...	12	32	0	Frick reaches top of long hill; descends. 5 m. behind Geiser.
...	...	...	...	...	...	12	36	5	Frick at valley beyond Straight St.
12	42	10	...	...	...	...	...	...	Geiser turns angle in Prospect Ave.
...	...	...	12	43	0	...	...	...	Huber passes Evan St.
12	44	10	...	...	...	...	...	...	Geiser turns short reversed curve, down hill; Prospect and Glenway Ave's.
...	...	...	...	...	...	12	50	0	Frick turns short reversed curve, down hill; Prospect and Glenway Ave's.
12	46	10	...	...	...	...	...	...	Geiser turns to the right into Tower Hill Road.

TABLE II., FIELD TRIAL—Continued.

Time of the events noted in margin at the right hand, with relation to the several engines named below; arranged in the order of starting.									
GEISER ENG.			HUBER ENG.			FRICK ENG.			NOTES AND REMARKS.
H.	M.	S.	H.	M.	S.	H.	M.	S.	
12	46	30	...	...	...	...	...	...	Geiser fairly entered on Tower Hill Road; grade about 1 in 10.
12	47	10	...	...	...	...	...	...	Geiser stops, 38 yards from foot of hill; road rough, soft and steep.
...	...	...	12	50	0	...	...	...	Huber reaches top of hill.
...	...	...	...	...	...	12	50	0	Frick passes short reversed curve, Prospect and Glenway Ave's; going nicely.
...	...	...	...	...	...	12	51	0	Frick reaches foot of Tower Hill Road, and waits in Carthage Pike for Geiser.
...	...	...	1	0	0	...	...	...	Huber reaches entrance to Park; loses 4 m., 30 sec. by going round.
...	...	...	1	1	0	...	...	...	Huber gearing out of order; ran too fast going down hill.
1	7	40	...	...	...	...	...	...	Geiser, after six ineffectual attempts, starting and stopping, and detaching the passenger wagon, starts with water and coal wagon, and goes along.
...	...	...	1	8	0	...	...	...	Huber loses pin out of steering-gear again.
1	8	10	...	...	...	...	...	...	Geiser reaches summit of Tower Hill Road.
1	10	15	...	...	...	...	...	...	Geiser turns to left from road upon rising natural ground.
1	11	10	...	...	...	...	...	...	Geiser runs against a small tree, 1¾ in. dia., on soft, steep ground.
1	11	15	...	...	...	...	...	...	Geiser stops; near driver turns and digs; off driver does not help.
...	...	...	1	15	0	...	...	...	Huber at Ludlow Ave.
...	...	...	1	20	0	...	...	...	Huber at Brooklyn Ave.
1	20	55	...	...	...	...	...	...	Geiser, after five ineffectual attempts, finally, at the sixth attempt, starts and goes along with the water and coal wagon, which were temporarily detached.
1	21	45	...	...	...	...	...	...	Geiser turns to left at top of hill; rad. of inside track, 15 ft.
...	...	...	1	22	0	...	...	...	Huber at Prospect Ave.
1	23	0	...	...	...	...	...	...	Geiser back in Tower Hill Road; steam pressure, 60 lbs.; stops to raise steam.
1	25	20	...	...	...	...	...	...	Geiser starts; steam pressure, 101 lbs.
1	26	15	...	...	...	...	...	...	Geiser back at turn of road, top of Tower Hill.
1	27	0	...	...	...	...	...	...	Geiser back at Carthage Pike, foot of Tower Hill.
...	...	...	1	27	0	...	...	...	Huber reaches Glenway Ave.
...	...	...	1	28	0	...	...	...	Huber reaches foot of Tower Hill; waits in Carthage Pike; a tooth of intermediate gear broken.

TABLE II., FIELD TRIAL—Continued.

Time of the events noted in margin at the right hand, with relation to the several engines named below; arranged in the order of starting.									NOTES AND REMARKS.
GEISER ENG.			HUBER ENG.			FRICK ENG.			
H.	M.	S.	H.	M.	S.	H.	M.	S.	
1	28	48	...	...	...	...	...	...	Geiser stops on Carthage Pike, 100 ft. below Tower Hill Road, to wait for the others to ascend Tower Hill.
...	...	...	...	...	...	1	31	0	Frick starts from Carthage Pike.
...	...	...	...	...	...	1	31	10	Frick at foot of Tower Hill.
...	...	...	...	...	...	1	32	10	Frick stops 70 yards from bottom of hill, 68 yards from top of hill, 32 yards above the place where Geiser stopped; steam pressure, 125 lbs.
...	...	...	...	...	...	1	33	0	Frick starts, with a pop! of safety valve, and goes along; 125 lbs.
...	...	...	...	...	...	1	33	15	Frick safety valve pops at 125 lbs., and whistle blows long and shrill.
...	...	...	...	...	...	1	34	5	Frick at top of Tower Hill.
...	...	...	...	...	...	1	34	15	Frick at turn of road.
...	...	...	...	...	...	1	35	20	Frick turns to left from road upon steep natural ground.
...	...	...	...	...	...	1	35	40	Frick stops; near driver slips and digs; off driver can not aid it. The natural slope of the ground, rudely measured, is about 1 in 15, but rising out of the rut it exceeds 1 in 4. One wheel slips, the other standing still. The large water wagon, constituting the whole load, is constantly attached, and with its narrow tire sinks deep in the soft yet tenacious ground. At 2.37.0 P. M. five or six men try to help by pushing, but accomplish nothing.
...	...	...	...	...	...	2	40	0	Frick, on the 38th attempt, after 37 ineffectual attempts, starts and goes along with his entire load, at 2.40.0.
...	...	...	...	...	...	2	41	0	Frick reaches top of hill, and turns as Geiser did, but in the opposite direction.
...	...	...	...	...	...	2	42	20	Frick back in road.
...	...	...	...	...	...	2	42	30	Frick stops near where Geiser did; plenty of steam, but some difficulty in turning; runs one fore wheel into a gutter. After backing and starting five times, "cutting" the fore wheels.
...	...	...	...	...	...	2	49	42	Frick starts and goes along at 2 h., 49 m., 42 sec.
...	...	...	...	...	...	2	51	0	Frick at turn in road, top of Tower Hill.

TABLE II., FIELD TRIAL—Continued.

Time of the events noted in margin at the right hand, with relation to the several engines named below; arranged in the order of starting.									NOTES AND REMARKS.
GEISER ENG.			HUBER ENG.			FRICK ENG.			
H.	M.	S.	H.	M.	S.	H.	M.	S.	
...	...	...	...	...	...	2	52	40	Frick at foot of Tower Hill Road, in Carthage Pike.
...	...	...	...	...	...	2	53	15	Frick halts in Carthage Pike, in position behind Geiser.
...	...	...	2	56	25	...	...	...	Huber starts from Carthage Pike; steam pressure, 100 lbs.
...	...	...	2	56	55	...	...	...	Huber turns up Tower Hill Road. No load but water and coal wagon.
...	...	...	2	59	0	...	...	...	Huber safely over bad places in road where the others stopped.
...	...	...	3	0	15	...	...	...	Huber at turn in road at top of hill.
...	...	...	3	1	10	...	...	...	Huber turns off from road upon rising natural ground.
...	...	...	3	1	55	...	...	...	Huber past the places where the others stopped.
...	...	...	3	2	59	...	...	...	Huber turns at top of hill on natural ground, as the others did.
...	...	...	3	4	0	...	...	...	Huber turns back into road.
...	...	...	3	7	10	...	...	...	Huber takes position in Carthage Pike behind Frick.
3	11	15	3	11	15	3	11	15	All start together to return; 20 ft. apart: Geiser, Frick, Huber.
3	11	15	3	11	23	3	11	19	Equated time of starting; passing Geiser's position.
...	...	...	3	17	30	...	...	...	Huber's steam gauge out of order. Engine running nicely up long hill.
3	20	30	...	...	...	...	...	...	Geiser reaches top of long hill: Forest Hill.
3	20	45	...	...	...	...	...	...	Geiser turns to right hand from Forest Ave. into Rockdale Ave., after slight descent.
...	...	...	...	...	...	3	21	55	Frick reaches top of long Forest Hill.
...	...	...	...	...	...	3	22	20	Frick turns from Forest Ave. into Rockdale Ave.
...	...	...	...	...	...	3	25	15	Frick at corner of Rockdale and Burnet Ave's.
...	...	...	...	...	...	3	26	0	Frick crosses soft place at Narrow Gauge Railroad Crossing.
...	...	...	3	29	50	...	...	...	Huber reaches corner of Rockdale and Burnet Ave's.
...	...	...	3	30	50	...	...	...	Huber reaches soft place at Narrow Gauge Railroad Crossing and stops.
...	...	...	...	...	...	3	31	0	Frick stuck in muddy place; drivers slid off from hard road into deep mud.
...	...	...	3	33	10	...	...	...	Huber starts and goes along. Steam gauge useless and steam low.
...	...	...	...	...	...	3	33	10	Frick stuck in mud 12 in. deep; detaches wagon.
...	...	...	3	36	30	...	...	...	Huber stops to repair eccentric; driver's seat broken.

TABLE II, FIELD TRIAL—Continued.

Time of the events noted in margin at the right hand, with relation to the several engines named below; arranged in the order of starting.									NOTES AND REMARKS.
GEISER ENG.			HUBER ENG.			FRICK ENG.			
H.	M.	S.	H.	M.	S.	H.	M.	S.	
...	...	...	...	...	...	3	52	0	Frick's revolutions-counter broken.
...	...	...	...	...	...	3	53	35	Frick reaches corner of Moliton and Vine Sts.
4	0	30	...	...	...	...	...	...	Geiser up over sharp ascent and reversed curve, Prospect and Glenway Ave's.
...	...	...	...	...	...	4	6	40	Frick reaches reversed curve, Prospect and Glenway Ave's.
...	...	...	...	...	...	4	7	45	Frick up steep ascent; where Geiser was at 4.0.30; diff., 7 m., 15 sec.
...	...	...	4	12	0	...	...	...	Huber reaches front gate of Zoological Garden.
...	...	...	4	21	40	...	...	...	Huber reaches reversed curve, Prospect and Glenway Ave's.
...	...	...	4	22	30	...	...	...	Huber at Prospect Ave.
...	...	...	4	23	20	...	...	...	Huber up steep ascent, Prospect Ave. and Glendale Ave. 22 m., 50 sec. behind Geiser, and 15 m., 35 sec. behind Frick.
...	...	...	4	23	40	...	...	...	Huber stops to oil something.
...	...	...	4	24	15	...	...	...	Huber starts and goes along.
...	...	...	4	26	8	...	...	...	Huber stops again to repair.
...	...	...	4	29	6	...	...	...	Huber starts again.
...	...	...	4	32	0	...	...	...	Huber at Brooklyn Ave.
...	...	...	4	34	0	...	...	...	Huber stopped at Ludlow Ave. to inspect feed pump.
...	...	...	4	38	0	...	...	...	Huber stopped. Pulley fell off.
...	...	...	4	40	0	...	...	...	Huber starts. Pulley put back in place.
4	43	50	...	..	...	...	...	...	Geiser reaches Exposition Building. End of run.
...	...	...	4	50	0	...	...	...	Huber reaches Park Entrance.
...	...	...	...	...	...	4	50	0	Frick reaches Exposition Building. End of run.
...	...	...	4	58	7	...	...	...	Huber turns at top of grade into Clifton Ave.
...	...	...	5	16	0	...	...	...	Huber reaches Vine St.
...	...	...	5	21	0	...	...	...	Huber reaches Race St.
...	...	...	5	30	5	...	...	...	Huber reaches Fourteenth St.
...	...	...	5	34	0	...	...	...	Huber reaches Exposition Building. End of run.

GENERAL REMARKS.

The incidents of the trial are all so fully detailed in the preceding log, although somewhat condensed, that it seems unnecessary to go over in detail all the adventures and misadventures of each engine. I will, therefore, confine myself to such general comments as may occur to me, in almost any order in which they may present themselves, often by comparison of one engine with another.

The conspicuous defects of workmanship in the Huber engine proved their serious importance by the frequent "accidents" which befell this engine. Its peculiar form of corrugations on the face of its driving wheels demonstrated its unfitness for all conditions of road, by the extreme difficulty with which the engine was made to cross street railways; but it may answer well on some farming land. Its great climbing qualities, due in part to its large factor of traction (l. 280, Table I.), and in part to the contrivance for coupling the two driving wheels together, were demonstrated at Tower Hill, where it passed in 10 m., 15 s., over the route which detained the Geiser engine 42 m., 38 s., and the Frick engine no less than 1 h., 22 m., 5 s. In performing this feat the Huber drew up Tower Hill 2,350 lbs., equal to 28·7 per cent. of its own weight in running order (l. 291), and 33·5 per cent. of its own net weight (l. 293); while the Geiser had, in going up this same hill, 3,181 lbs., only 23·7 per cent. of its own weight, with water and fuel (l. 291), and 27·3 per cent. of its own net weight (l. 293). The Frick engine had much more than either of the others, namely: 6,168 lbs., equal to 47·1 per cent. of its weight in running order, and no less than 57·9 per cent. of its own net weight. This performance of Mr. Frick's engine displayed great staying qualities on the part of man and engine alike; but the method he pursued would enable any engine to get out of any hole in time. This method consisted of macademizing the rut under the sunken wheel with stones, alternately before and behind the wheel, and running forward and back upon the causeway so formed, until the wheel was lifted high enough to run off upon the ground in front of it, not too far from a level. To persist in doing this for more than an hour, with three tons load on behind, was plucky, and in the end successful; but it could have been done in less time if the load had been detached and again picked up after "treading the road."

I was watching the Geiser engine when the near driver struck the small tree mentioned in the log—stood within a yard of the tree—and am confident that but for this tree the engine would have gone along without stopping. The ground was no worse than that already passed

over for several yards; but the tree bent to the curve of the tire, its bark was instantly scraped off, and the slimy surface of the naked wood offered no hold for the corrugations of the tire, while preventing them from taking hold of the ground in front of the wheel. The remarkable ease with which the equalizing gears ran, noticeable at the Exposition, permitted this wheel to turn freely while the other remained motionless, and the corrugations dug a pit ever deeper for the idly revolving wheel.

It was the opinion of several competent witnesses, as well as my own opinion, that the ordinary device of locking the equalizing gears would have enabled both the Geiser engine and the Frick to go over the entire route, actually run, with little detention, if any.

The performance of the Geiser engine, in running up Vine Street Hill, was every way admirable. The Frick did almost as well, and would, I think, have done quite as well had its valve been properly set. The same inequality of the two strokes which showed itself in the friction card, with 10 lb. spring, and in all the diagrams at the economy trial, is seen in diagram No. 4 (p. 85), one of three all much alike, taken at 1 h., 46 m., 0 s., P. M., while the engine was struggling in the hole on Tower Hill.

The five cards from the Geiser engine (Nos. 5–9) show the same persistency of qualities and defects.

It will be observed that in these cards the strokes are transposed from their position in the one given above as a mean of all the diagrams taken at the economy test; while the one below, from the Frick engine, is not so transposed. This is on account of the way in which the indicators happened to be adjusted. The five diagrams from the Geiser engine, under various conditions, are very instructive.

Supposing the speed to be uniformly as during the economy trial, *i. e.*, controlled by the governor, the power required on a level road was 4·36 I. H. P. (4 h., 35 m., 0 s., P. M.). Again, also on a level road, but presumably a worse one, at 3 h., 47 m., 0 s., 12·93 I. H. P. Going up the steep Vine Street Hill, road very smoth, 16·11 I. H. P. At the steep grade, on soft ground, at the reversed curve, Prospect and Glenway Avenues, the mean effective pressure, with normal speed, would represent 27·22 I. H. P.; while, just before stopping, 1 h., 11 m., 10 s., a pressure was exerted in the cylinder, which, at normal speed, would be capable of exerting 32·54 I. H. P.

The mean of all observed steam gauge pressures, pretty regularly taken during the run, are:

Huber	98·12	pounds per square inch.		
Frick	116·9	"	"	"
Geiser	115·6	"	"	"

These pressures are probably all subject to four or five pounds reduction, on account of the softening of the springs at the steam gauges by heat, as already explained with regard to ll. 88, 89, Table I.

While it is certain that in this competition the engine of the Geiser Manufacturing Company is the victor at all points, it is by no means certain that it is to the same degree superior to its nearest rival, the Frick engine.

I have presented elsewhere my views upon the chief points of difference between them. Both were in perfect order during and after the trial; both are good engines, and I predict for both a great future, when they are made to do their work with an expenditure not exceeding thirty pounds of water per horse-power (indicated), and per hour.

I desire, in conclusion, to tender my sincere thanks to the assistants who gave me most valuable aid, with untiring devotion, especially Mr. Walter Laidlaw, Prof. R. B. Warder, and Mr. E. H. St. John. Of Mr. Frank Lederle's assistance, in making planimeter measurements of diagrams, I have spoken elsewhere. I regretted the too early privation of Mr. Newton M. Anderson's assistance. Mr. Harry M. Lane, Mr. F. Bain, Mr. E. A. Edwards, and Mr. Alfred R. Payne, also gave valuable help, particularly at the field trial.

TABLE OF GRADES IN THE ROUTE OF THE FIELD TRIAL. See foot note, p. 82.

Length of Interval, in feet.	Whole Distance from the Start, in feet.	Rise or Descent, in feet per hundred.	
	0		Power Hall.
100	100		Fourteenth and Plum Streets.
405	505	—*0·5	Fourteenth and Elm Streets.
470	975	0·8	Fourteenth and Race Streets.
1010	1985	—0·7	Race and Liberty Streets.
1305	3290	1·9	Race and Findlay Streets.
470	3760	2·23	Findlay and Vine Streets.
560	4320	4·0	Vine Street and Clifton Avenue.
1700	6020	8·48	Clifton Avenue.
500	6520	6·59	
210	6730	5·14	Clifton Avenue and Parker Street.
490	7220	5·14	
1085	8305	7·96	McMillan Street.
235	8540	—5·34	Calhoun Street.
350	8890	3·49	

*A descent in the grade is indicated by the minus sign.

TABLE OF GRADES—Continued.

Length of Interval, in feet.	Whole Distance from the Start, in feet.	Rise or Descent, in feet per hundred.	
120	9010	1·0	Clifton Avenue.
900	9910	—6·0	
700	10610	2·0	
700	11310	—3·5	Park Entrance on Clifton Avenue.
1000	12310	—3·4	
1300	13610	—5·46	
1000	14610	2·7	North Line of Ludlow Avenue.
500	15110	—1·8	Brookline and Prospect Avenues.
600	15710	—1·5	
450	16160	—9·0	
170	16330	—10·0	Glenway Avenue and Carthage Pike.
100	16430	—10·0	
250	16680	—7·0	Carthage Pike and Tower Street.
450	17130	11.78	Tower Street and Belvedere Street (Top of "Tower Hill").
450	17580	—11.78	Tower Street and Carthage Pike.
1330	18910	—2.8	Carthage Pike and Forest Avenue.
840	19750	2·38	
710	20460	4·65	
1240	21700	8·71	
58	21758	7·0	
172	21930	—1·16	Forest and Rockdale Avenues.
400	22330	1·25	Angle in Rockdale Avenue.
840	23170	—0·6	Rockdale and Burnet Avenues.
650	23820	0·61	
763	24583	3·4	Section Line, Corryville.
855	25438	4·0	
1412	26850	1·0	Burnet Avenue and Shillito Street.
430	27280	—2·84	Shillito Street and Highland Avenue.
400	27680	—6·42	Shillito Street and Bellevue Avenue.
750	28430	—1·0	Bellevue Avenue and Donahue Street.
250	28680	4·83	Bellevue Avenue and Hammond Street.
460	29140	—3·55	Hammond Street and Eden Avenue.
960	30100	5·17	Hammond and Vine Streets.
180	30280	0·4	Hammond and Falke Streets.
890	31170	—2·75	
180	31350	3·9	
1725	33075	—3·08	
2075	35150	—5·56	
100	35250	10·0	Glenway Avenue and Carthage Pike.
170	35420	10·0	
450	35870	9·0	
600	36470	1·5	Brookline and Prospect Avenues.
500	36970	1·8	North Line of Ludlow Avenue.
1000	37970	—2·7	
13610	51580		Power Hall.

The route, in returning from Glenway Avenue and Carthage Pike, was the same as in going out. Fourteenth, Race, Findlay and Vine Streets are paved with bowlders; those beyond are macadamized. There was an upward grade of 4% or more, for an aggregate distance of 10,923 feet, or full 21% of the whole route. The average grade in these portions was 7·5%.

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American Journal of Education, February, 1882.
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From the Authors.

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SCIENTIFIC PROCEEDINGS

OF THE

OHIO MECHANICS' INSTITUTE.

VOL. I. JULY, 1882. NO. 3.

PROCEEDINGS OF THE DEPARTMENT OF SCIENCE AND ARTS.

Meeting of April 13.

THE Special Committee of March 9 reported that they had met with the "Cincinnati Forestry Club," but the proposed union is not yet effected.

Professor R. B. Warder offered the following:

"WHEREAS, A scientific body is soon to meet in Cincinnati in the interests of Forestry, a subject which is intimately connected with our future timber supply, our facilities for transportation, and amelioration of our climate; therefore,

"*Resolved*, That a committee be appointed to endeavor to secure the publication of such papers relating to forestry as may have a permanent scientific value."

The resolution was adopted, and Messrs. Warder, McMeekin and Osmond were appointed on the committee.

Professor O. Stone offered the following:

"*Resolved*, That a special committee of three be appointed to confer with committees from other bodies, to use their influence in procuring the necessary legislation to have scientific works in foreign languages admitted into this country free of duty."

This resolution was adopted, and Messrs. Stone, Clarke and Collord were appointed accordingly.

Professor F. W. Clarke then delivered a lecture upon "THE NATURE OF THE CHEMICAL ELEMENTS."

Meeting of May 11.

Professor R. B. Warder gave an outline sketch of "FORESTAL SCIENCE AND THE FORESTRY CONGRESS," showing the general scope of the scientific and practical information that is linked together in our woodland interests, and embraced by the courses of study in European schools of forestry. We can hardly recognize *a science* of forestry, since this subject presupposes a combination of the various natural and economic sciences as a foundation, to which many special details and applications

must be added. The subject matter of forestry (as of other industries), instead of running parallel to the various true sciences, embraces a portion of many, as illustrated by the following table:

FORESTAL SCIENCE INCLUDES.

GENERAL SCIENCE.	DETAILS AND PRACTICAL APPLICATIONS.
Botany—anatomy, physiology and classification of plants.	Dendrology—or the botany of trees—including geographical distribution, the variations produced by a change of conditions, diseases and their remedies.
Zoology, especially entomology.	Insect foes, birds, game, hunting and trapping.
Meteorology.	Influence of forests upon rain-fall, floods, atmosphere, miasma, and winds.
Geology, mineralogy, and physical geography.	Surface, soils, climate, and conditions of each State or Country. The trees and methods adapted to each.
Physics and chemistry—general, agricultural, and industrial.	Decomposition of rocks; composition and physical properties of soils; composition of plant tissues and sap; forces and phenomena of tree growth. Structure and physical properties of woods. Drugs and other chemical products of the forest.
Mathematics and engineering.	Mensuration of land, of lumber, and of standing timber; statistics of forest areas and timber supply. Laws of annual growth. Transportation; mills and machinery.
Finance and political economy.	Natural law of supply and demand in its special application to the forest resources of a country or countries. Provision for the more distant future, as well as for present demands.
Jurisprudence.	The duty of Government in administration, taxation or bounty, experimental stations, and education.

An acquaintance with all the subjects of this table may be needful to the forest engineer, who attempts to solve problems affecting the interests of a State. For the practical forester, in a particular location, a more limited range of information may suffice.

In the Forestry Congress recently held in Cincinnati, the scientific interests were chiefly due to the President of the American Forestry Association, who was supported by members of the Cincinnati Forestry Club and the Ohio Mechanics' Institute. About ninety papers were entered for reading, embracing a wide range of scientific and practical topics.

The following resolution, offered by Professor Warder, was adopted:

"*Resolved*, That the Board of Directors of the Ohio Mechanics' Institute be requested to consider the advisability of publishing the proceedings of the Cincinnati meeting of the American Forestry Congress, as a supplement to the first volume of our own Scientific Proceedings."

Meeting of June 13.

By the kind invitation of the Chairman, L. M. Hosea, Esq., this meeting was held at his residence.

A paper on "THE AURORA BOREALIS OF APRIL 16," by Chas. G. Boerner, of Vevay, Ind., was read by R. B. Warder.

The Chairman exhibited a section of a hot water pipe, from Longview Asylum, which had become completely choked with a deposit similar to ordinary "boiler scale." Messrs. Warder, Springer, Danks, and Payne were appointed a special committee to inform the Trustees of the Asylum of the nature of the difficulty and its remedy.

Professor R. B. Warder read a paper on "MALARINE," a proprietary article, advertised as a certain preventive of small-pox, etc. Chemical and microscopic examination shows this substance to be essentially the same as the antiseptic called "Ozone" (see p. 40). A partial analysis gave the following results: sulphur, 94.8 per cent.; carbonaceous residue, 4.2 per cent.; ash, 0.04 per cent.

Mr. L. M. Hosea announced that the Committee on a School of Technology was still at work, and that some courses of practical lectures, appropriate to this movement, would be given during the coming fall and winter.

The Department adjourned (after a time of social intercourse) to meet at the usual place in October.

PROCEEDINGS OF THE SECTION OF MECHANICS AND ENGINEERING.

Meeting of April 20.

Messrs. Stanwood, McMeekin, and Lane were appointed as a committee to prepare a plan for collecting data in regard to the proportions of boilers and engines.

Messrs. Warder, Robbins, and Baldwin were appointed a committee to collect manufacturers' catalogues, price-lists, etc., as requested by the United States Patent Office, retaining one set for the use of the Institute.

Mr. A. R. Payne then discussed the "SMOKE PREVENTING DEVICES EXHIBITED IN 1875 AND 1879," showing that smoke prevention and efficiency are two independent factors, in judging of their value.

Meeting of June 15.

Dr. James G. Hunt read a paper on "COMBUSTION OF FUEL," showing that false inferences regarding economy have been drawn, in certain

cases, from the absence of visible smoke, since there may be a great waste of hydrogen and the poisonous monoxide of carbon.

PROCEEDINGS OF THE SECTION OF CHEMISTRY AND PHYSICS.

April 27.

The meeting for this date was omitted on account of the "American Forestry Congress."

Meeting of May 25.

A note on "THE DETECTION AND ESTIMATION OF MANGANESE BY THE ELECTROLYTIC FORMATION OF PERMANGANATE," by Professor N. W. Lord, of Columbus, was presented by Professor F. W. Clarke. Professor Lord had obtained this reaction* distinctly in a solution containing one part of manganese sulphate to 100,000 parts of the fluid. The solution, free from HCl and HNO_3, but containing H_2SO_4, is put into a platinum dish, and a platinum wire just touching the liquid is made the positive pole of the current for one or two cells. In a few minutes, the purple color of the permanganate (not $Mn\ O_2$, as sometimes stated) is well developed. Other bases seem to have no influence; and this seems to be a convenient method of testing minerals for manganese, as it does not interfere with the usual course of the analysis. Professor Lord proposes to titrate the manganese, after oxidation, with $\frac{1}{10}$ normal oxalic acid. He is engaged in further experiments for this purpose.

The next paper was by Professor H. T. Eddy, upon "RADIANT HEAT AN EXCEPTION TO THE SECOND LAW OF THERMODYNAMICS."

Professor F. W. Clarke announced the following "TARTRATES OF ANTIMONY": Sb_2O_3, dissolved in tartaric acid and evaporated, yielded crystals of the acid tartrate,

$$Sb\begin{cases} C_4\,H_4\,O_6\ .\ H \\ C_4\,H_4\,O_6\ .\ H \\ C_4\,H_4\,O_6\ .\ H \end{cases} +3\ H_2\,O.$$

Upon adding alcohol to a solution of the foregoing salt, the normal tartrate was precipitated. The air dried salt has the composition

$$C_4\,H_4\,O_6{=}Sb{-}C_4\,H_4\,O_6{-}Sb{=}C_4\,H_4\,O_6{+}6\ H_2\,O.$$

Tartrantimonites of aniline, atropine and quinine were also described.

Professor R. B. Warder reported that in some preliminary experiments

*Described by Luckow in 1869, Zeitsch. anal. Chem., **8**, 24.

upon the "SPEED OF SAPONIFICATION BY BARIC HYDRATE," the reaction,

$$2\ C_2H_5 . O . C_2H_3O + Ba(OH)_2 = 2\ C_2H_5 . OH + Ba . O_2 . (C_2H_3O)_2$$

proved to be nearly as rapid as the action of sodic hydrate under like conditions of temperature and dilution. Compare *American Chemical Journal*, **3**, 340.

Dr. A. Springer stated that butyric acid and butyrates interfere with the iodine reaction for starch.

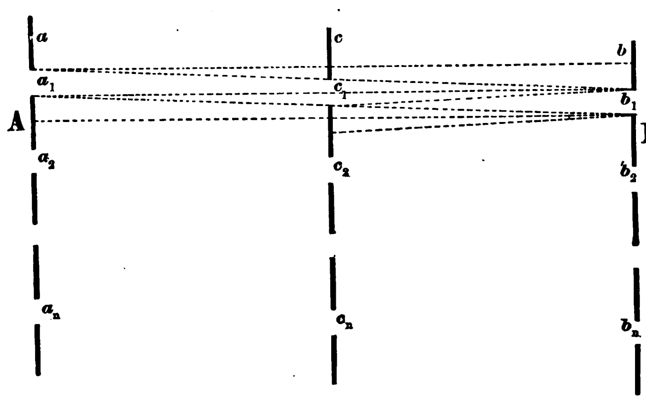
The section then adjourned to meet at the usual time and place in September; or, if practicable, to hold a special meeting in Montreal next August.

X.—RADIANT HEAT AN EXCEPTION TO THE SECOND LAW OF THERMO-DYNAMICS.

BY H. T. EDDY, PH. D.

[Read before the Section of Chemistry and Physics, May 25, 1882.]

SINCE the radiation of heat takes place by propagation through space at a certain finite velocity, and not instantaneously, it is quite possible for occurrences to intervene during the exchange of radiations between two bodies, such as to essentially change the distribution of heat which would otherwise have ultimately taken place.



To make this evident, let us first employ a mechanical analogy. In the accompanying figure, let there be three parallel screens *a*, *b*, and *c*, the latter between the two former, and all three perpendicular to the plane of the paper. Let them be pierced respectively by a series of equidistant apertures $a_1\ a_2\ a_n$, $b_1\ b_2\ b_n$, $c_1\ c_2\ c_n$, situated in the plane of the paper,

and let these apertures be so placed that a_1, b_1, c_1, are upon one straight line, not quite at right angles to the screens; then are a_2, b_2, c_2, etc. and a_n, b_n, c_n, upon lines parallel to a_1, b_1, c_1. Now conceive the screens a, b, c, to have a common uniform velocity, u, in the direction from c_2 to c_1. Also, let a series of projectiles be discharged from any fixed position, A, at the left of the screen a, at such instants as to pass the first one through the aperture a_1, the second through a_2, etc., and let the direction of discharge be perpendicular to the screens, and the velocity, v, such that each one shall just reach the screen b in time to pass through the first aperture of that screen which crosses its path. Then would the screens a b c in no way interfere with the passage of these projectiles. Let us denote the space at the left of a as the space A, and that at the right of b as the space B. Then, if there be a continuous discharge of projectiles from all points of the space A, only a part of them can pass through the apertures of a. Such, however, as succeed in passing a, will pass b and c also. Again, let a second discharge of projectiles take place from the space B, but directed toward the left perpendicularly to the screens, so that these projectiles move in a precisely opposite direction from those first mentioned. Let the projectiles from B have the common velocity v'. Such of these projectiles as succeed in passing through the apertures of b will impinge on c at points between its apertures, in case c be placed at a proper distance from b. Let the surface of c which faces b be perfectly reflecting, and let the parts between its apertures be either concave, or a series of inclined planes, so directed that each of the projectiles on rebounding will pass back through one of the apertures in b. When the velocity v' of the projectiles is large compared with that of the screens u, the projectiles can be made to return through b very nearly perpendicularly, either by returning each projectile through that aperture from which it started or through some following one.

The paths of the projectiles relative to the screens can be readily found by impressing upon the projectiles, in addition to their velocities v or v', a velocity $-u$, numerically equal and opposed to that of the screens, while the screens themselves are at rest. The composition of these velocities will give the required relative velocity.

In order to apply the mechanical analogy just considered to the case in hand, let us replace the supposed projectiles by radiations which emanate from warm bodies situated in the spaces A and B, and let the only radiations at first considered be those in a direction perpendicular to the screens.

It is then evident that with such a series of apertures as are represented

in the figure, the screens a b c could be given such a velocity u, as, accompanied by reflections from c, would transfer radiations from the body A to B, unaccompanied by a compensating transfer from B to A; and thus the body B would be heated at the expense of A. Even if radiations at the apertures in a and b be not confined to rays perpendicular to the screens, but take place instead in the manner usual at plane surfaces, it is still evident that the usual interchange of radiations has been effectively interferred with, and that the body B would be heated at the expense of A. In case the radiations from the body B are reflected back through the same apertures from which they started, it is quite unnecessary to have the series of apertures in the screen a at equal distances; it is only necessary that the series of apertures in b and c correspond to those in a. Indeed, each aperture in b can be conceived to be completely surrounded by a concave semi-cylindrical reflector, attached to c, of such a form as to return to b all radiations from it when moving with the velocity u. This can certainly be effected if the apertures in b are mere points, and can be closely approximated to when they are small. Now, if there be in this cylinder a proper aperture for the admission of the normal radiations from A through a, it is evident that the radiations passing through this aperture from B, being oblique, are, when the bodies are of equal temperature, less than those of A passing through the same aperture, according to the well known law of radiations that the intensity is proportional to the cosine of the angle between the ray and the normal to the radiating surface. It is seen that with a sufficiently large value of u, it would be possible to overcome any difference of temperature, however great.

In order to form an estimate of the amount by which the radiation from A to B exceeds that escaping from B through c, let us suppose that the temperatures of A and B are equal, and that the velocity v of the radiations from both A and B is the same; and, further, let the screen c be midway between a and b at a distance p from each. Let the problem be to compute the ratio between the radiations which pass through a given aperture, as c_1, from a_1, and from b_1, respectively, on the supposition that the heat radiates from the equal apertures a_1 and b_1, as from plane surfaces, in the usual manner.

Suppose that the linear dimensions of the apertures are infinitesimal compared with p, and let the letters a_1 b_1 c_1, considered as numerical magnitudes, designate the areas of the apertures a_1 b_1 c_1 respectively. Let θ be the angle between a ray and the normal to the surface from which it radiates. Let a sphere of radius p be supposed to be described about some point of b_1 as a center, and let s be the area of that part of its

surface included within the cone of rays passing from the center to the periphery of the aperture c_1;

$$\text{then } \frac{s}{p^2}=\frac{c_1}{r^2}\cos\theta \qquad (1)$$

in which r is the distance passed over by the ray from b to c.

$$\text{Also } p=r\cos\theta \qquad (2)$$

$$\text{therefore } s=c_1\cos^3\theta \qquad (3)$$

Now the heat radiated from b_1 is directly proportional to the area b_1, to the area s, and to $\cos\theta$, but inversely proportional to p^2;

$$\text{hence } \frac{b_1\, s}{p^2}\cos\theta=\frac{b_1\, c_1}{p^2}\cos^4\theta \qquad (4)$$

is proportional to the heat radiated from b_1 through c_1.

Similarly, $$\frac{a_1\, c_1}{p^2} \qquad (5)$$

is proportional to the heat radiated from a_1 through c_1, since it passes c normally. Now the heat passing from b_1 to c_1 must evidently move in a direction to overtake the aperture c_1, and to do this it must evidently take a direction such that θ is defined by the equation

$$\tan\theta=\frac{2u}{v},\ \text{or}\ \cos^2\theta=\frac{v^2}{v^2+4u^2} \qquad (6)$$

Hence, by comparing expressions (4) and (5), and substituting from (6), it appears that the heat radiated from a_1 through c_1 is greater than that radiated by an equal surface b_1 through c_1, in the ratio of $(v^2+4u^2)^2$ to v^4, in case the temperatures of a_1 and b_1 are equal. If the temperature of a_1 were lower than that of b_1, this ratio would be diminished; but by increasing u, the ratio can still be made to exceed unity, thus confirming the observations previously made. Neither is it essential that the radiations all take place at the same velocity. The reflectors can be arranged for some one velocity, and they will then send back the radiations to B which have that velocity.

Perhaps the most simple ideal arrangement for effecting the proposed interference with the radiations naturally taking place between two bodies, is to suppose the apertures distributed around the circumferences of equal circles, upon three parallel disks fixed upon a common central axis, so that the plane of the paper in the figure becomes the surface of a circular cylinder; in which case the required velocity u can be given to the apertures by simple rotation. Let us for brevity call such an arrangement a *radiation syren*, or simply a *syren*, as it slightly resembles in its mechanical details the acoustic instrument called by that name. Now,

theoretically, no expenditure of energy is necessary to preserve the uniform velocity of the moving parts of this syren; and, once started with a sufficiently high velocity of rotation and proper adjustment of reflectors, it would transfer heat from the body A to B, regardless of their temperatures, provided no radiations are permitted except those perpendicular to the disks, excluding of course all radiations to and from all bodies other than A and B. It would also, as before shown, transfer heat from a colder body to a hotter, even though the radiation follow the general law of radiations from plane surfaces.

It is needless to state that the action of the syren, regarded as a possible physical process, is directly at variance with hitherto accepted axioms and conclusions respecting the second law of thermo-dynamics. It is true, we should at first thought be inclined to the belief that the laws of heat should suffer some modification, in case we assume differing rates of propagation not infinite, but we should hardly be prepared to admit the startling conclusions which must flow from such modification, if the physical process just sketched be admitted to be valid; and these I shall now proceed to develop.

I think it may be readily perceived that the axioms of Clausius, upon which he founds the second law, viz., that "heat can not of itself pass from a colder into a hotter body," when applied to radiations, implicitly assumes that the heat is radiated with infinite velocity; for it takes no account of the states of relative rest or motion of the bodies between which heat passes.

The axiom of Thomson, "It is impossible, by means of inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of surrounding objects," is obnoxious to the same criticism; and, as I have stated elsewhere,* these should not be called *axioms* at all, since we are not in a position to bring sufficient experience to bear upon them to affirm their validity or want of validity. Indeed, if the process of the syren be admitted to be possible, we are now in a position to assert that there exists an unexplained contradiction, which does not permit us to consider them as applicable to radiations of heat propagated at finite velocities.

What, it seems to me, the statements of Clausius and Thomson just quoted, really asserted, was the historical fact that at the date when they were made no one had as yet invented any machine, or discovered any principle on which it was possible to construct a machine, which could

*Thermo-dynamics, New York, 1879.

successfully accomplish what these said had not been done; and it was further implied that no such machine could probably ever be invented, nor any such principle discovered.

In complete accord with this statement is that of Kirchhoff, made, in his lectures upon the Theory of Heat during the summer semester of 1880, in which he said, if correctly reported, that the second law can not be (at present) proved; but it, so far, has never been found in disagreement with experience.

It is well known that Maxwell has proposed a process to accomplish this very object; namely, to transfer heat from a colder to a hotter body, in the following manner: If we suppose minute beings, endowed with senses sufficiently acute, and having a corresponding agility, to guard minute openings in the diaphragm separating two portions of the same gas, which openings are only large enough for a single molecule to pass at once, they would be able, without expenditure of energy, to open and close the openings in such a way as to allow each molecule impinging at an opening to pass through or not, as they should choose. If they permitted only those molecules having more than the mean *vis viva* to pass in one direction, and only those having less than the mean to pass in the opposite direction, then the gas in one side of the diaphragm would gain energy at the expense of that on the other side. That this process is actually at present beyond human ability, does not show that we may not at some future time be able to accomplish what Maxwell proposed. If this be admitted, then the conclusions which I shall draw later from the lack of generality in the second law of thermo-dynamics flow, to a limited extent, from the possibility of this process. But Maxwell's process assumes the kinetic theory of gases as its basis, and stands or falls with it. And if the second law is a necessary ultimate mechanical principle, holding for all bodies great and small, the above consequence of the kinetic theory of gases, being in contradiction to the second law, is fatal to the validity of the kinetic theory. But I do not now so regard the second law. I am compelled to regard it as merely an approximation in the case of radiations, and to regard it in general, with Maxwell and with Boltzmann,* as merely the mean result flowing from the laws of probability, though it had previously seemed to me possible to show it to depend upon fundamental considerations, respecting the nature of heat as a form of energy, as was stated in my work previously referred to.

To avert to the consequences which are thus made to flow from the

*Wein. Sitzb., Bände LXXVI, LXXVIII.

established fact of the finite velocity of radiant heat, we may mention that if the law of the dissipation of energy is no longer to be regarded as of universal validity, it being obviated by the process of the syren, it is just as possible to avail ourselves of the heat stored in cold bodies as in hot ones, and thus to employ the heat of a glacier to drive a steam-engine, or to perform other like feats heretofore regarded as impossibilities. When I say it is just as possible, I do not imply that it is now just as practicable, or, perhaps, ever will be so. That these observations are just, is seen when we reflect that the process of the syren simply heats a given body at the expense of any other, regardless of temperatures, by a method requiring the expenditure of no energy. It thus appears that it is possible to avail ourselves of the heat existing in bodies below the lowest thermometric levels of surrounding objects.

It may be objected that the syren renders a perpetual motion a possibility. That depends upon the definition of perpetual motion which we adopt. In the popular acceptation of that term, the process of the syren, as well as that of Maxwell, would make something near that possible. But when correctly viewed, the process of the syren does not imply the possibility of a perpetual motion, any more than does combustion or using the available energy of any chemical process. It simply proposes to employ the finite amount of energy existing in a given body, in the form of heat, in a given way.

It is admitted by all that that heat could—a part of it—be made to do work by parting with some of it to a cooler body. The question is whether this last part, which has been imparted to a cooler body, can be restored or transferred to the warmer body again without the expenditure of energy. Rankine evidently believed such a transfer possible; for, in a paper on the "Reconcentration of the Mechanical Energy of the Universe,"* he has supposed it possible to reflect radiations in such a way as to give the universe such differences of temperature as to insure it a new lease of life. Clausius, in his admirable paper on the "Concentration of Rays of Light and Heat,"† has shown the general impossibility of such a reconcentration as Rankine supposed, when the radiating bodies are at rest; nevertheless, no such impossibility may finally appear in case of the actual universe, which is a system of moving bodies.

The law of the dissipation of energy has been applied to the universe at large, and if the consequences which have been drawn from its

*Philosophical Magazine [4] 4, 358.
†Mechanical Theory of Heat, Chapter XII.

supposed validity are to be regarded as no longer expressing a necessary law, then we are led to affirm that without a change in the laws of nature, as at present known to us, it is possible for increasing differences of temperature to be caused without the expenditure of energy, however improbable the supposition may be that such is the fact, and however improbable it may be that such differences are actually being caused on a scale sufficient to interfere in any practical way with the progress of the dissipation of energy, as affirmed by Thomson, or check the increase of the entropy of the universe, as stated by Clausius. Still it may be remarked that a large part of the exchange of heat in the universe takes place in the radiant form; and, it seems to me, that it remains to be proved what the fact actually is, and consequently I must regard it as still an open question, as to whether on the whole the available energy of the universe is being dissipated, and its entropy increased or not.

Lest the foregoing remarks should be construed as in any sense undervaluing the splendid discoveries of Clausius, Thomson and Rankine in the domain of thermo-dynamics, let me disclaim such an interpretation entirely, and say that my only wish is to add, if possible, to the exactness and completeness of those theories, which are among the most important of modern physics.

UNIVERSITY OF CINCINNATI, O., *April* 22, 1882.

NOTE.—Professor J. Willard Gibbs has suggested to me that we are not at liberty to assume that reflections or radiations taking place at moving surfaces follow the same laws as from surfaces at rest; and that a perfect reflector, moving in a medium through which luminous waves are being propagated, may suffer a resistance which would require the expenditure of as much energy as could be obtained by the proposed process. Admitting for the moment the justness of these observations respecting reflections and radiations from moving surfaces, I shall hope to show, in the first place, that the syren may be so adjusted that no such resistance need be encountered, and in the second place, that it is possible so to modify the syren that no reflections or radiations need take place from moving surfaces.

In the discussion of the first point, let us consider the case of a ray falling perpendicularly upon a perfect reflector. The only numerical magnitudes susceptible of variation in this radiation are its wave length and amplitude, the velocity being assumed constant and dependent upon the elasticity of the medium. When the reflector moves in its own plane at right angles to the ray, it can not, apparently, be seriously urged that

the reflected ray will have either its wave length or its amplitude changed by the reflection. For, so far as can be seen, the wave length would suffer a change and be shortened only by giving the reflector a motion toward the approaching ray, thus crowding the waves together. Neither would the amplitude be changed, for to do this would require the moving plane to impart tangential impulses to the ether, such as can be compounded with the transverse motions already existing. If such be the tangential action of the moving plane on the ether, we should be led to the apparently inadmissible result, that since a moving plane may impart tangential impulses to the luminferous ether, a disk rotating with sufficient velocity in vacuo would become self-luminous.

It would seem but reasonable, in our present imperfect knowledge of the subject, to conclude that the only resistance which a perfect reflector experiences while moving against a ray is normal to its surface, and to be represented by a normal pressure. Even if this view be not regarded as entirely correct, it may, nevertheless, be confidently affirmed that the tangential must be small compared with the normal resistance, just as a frictional resistance of a gas is small compared with that arising from direct pressure upon a body moving through it. Hence it is seen that in spite of friction, it is possible to make a ray turn a mill whose vanes are perfect reflectors, in the same manner as the wind turns a wind-mill; and the energy expended will in that case be withdrawn from the ray itself. Now the rotating screen c of the syren may be regarded as such a mill, the surfaces of whose vanes may be so inclined as to return radiations coming from B, partly to apertures in front of those from which they emanated, and partly to those behind, so as to exert no force either to accelerate or retard c. Should, however, energy be expended in moving c against the reflected ray, this energy must exist immediately after the reflection in the reflected ray, and be transmitted by it to B. Hence we are led to the following remarkable result: On the hypothesis that radiations cause pressure at surfaces at which they suffer total reflection, a part of the energy of the radiation may be expended in moving the reflector against a resistance, while the remainder is all reflected to the body from which it emanated. It is to be noticed that this process of the *reflecting mill*, or *mill* as it may be called for brevity, is, if possible, in more pronounced and unequivocal contradiction to the second law than that of the syren. For the latter calls in question the accepted law of mutual exchanges, and the second law as depending upon it; but the former applies to a single body alone, as B, and a moving reflector. For example, let B have no radiations except those through the apertures b; then if that part of its radiations

which are not expended in turning c are returned to it, it is possible for the mill c to be turned by radiations from B, until the energy of B is all expended in performing work, thus withdrawing all heat from B, while no heat has been transferred to any other body in the manner required by the second law, and this regardless of the temperature of surrounding objects. It therefore seems to me that the supposition of a pressure at reflecting surfaces is more directly opposed to the second law than that of no pressures.

In regard to the second point mentioned, it seems quite possible to construct a syren such that the reflections in it shall all take place from stationary surfaces, or from those whose velocity differs from zero by less than any assignable quantity. For, let the mean velocity u of the screens be the same as before, but not continuous. Instead, let its motion consist of sudden steps forward, each of which is half the width of an aperture. The possibility of a mechanical arrangement, which could effect this motion without expenditure of energy, with the aid of perfect springs, fly-wheels, detents, etc., to any required degree of approximation, will, I think, be admitted, certainly by any one who can admit that Maxwell's "sorting demon" expends no energy in opening and closing apertures. It will be seen that the reflections all take place from screens at rest (or nearly so) in this modified syren, and that the same transmissions occur through its apertures as have heretofore been supposed to take place. I am not inclined, however, to insist on the special kind of apparatus which I have proposed for rendering sensible the phenomenon which I believe to exist during the time in which radiations are in process of becoming established, as contemplated in the ordinary law of thermal exchanges. The point to which I would emphatically direct attention is, that since radiations are known to be moving in space apart from ponderable bodies, and subject to reflections, it is possible so to deal with them as to completely alter their destination, and successfully interfere with all results flowing from Prevost's law of Exchanges. It also seems to me that the exactness of the second law of thermo-dynamics depends, as far as radiations are concerned, upon that of this law of exchanges.

CINCINNATI, *May* 18, 1882. H. T. E.

XI.—SMOKE PREVENTION IN ENGLAND.

By Harry M. Lane, M. E.

[Abstract of a Lecture read before the Department of Science and Arts, June 7, 1881.]

As early as 1306, in consequence of a petition from Parliament, King Edward I. prohibited "the burneing of sea cole in London and the suburbs, to avoid the sulferous smoke and savour of the fireing." The penalties imposed during that reign were a fine, destruction of the furnace, and even the death of the culprit.

In the years 1819 and 1843, select committees were appointed by the House of Commons, to investigate, and to prepare bills for smoke prevention. The "Leeds Improvement Act" was due to the latter committee; and this is a fair specimen of the numerous local enactments now in force.*

Perfect combustion yields a mixture of invisible gases and vapor. Smoke, as generally understood, contains solid particles of carbon also; and "smoke-prevention" means the prevention of these visible particles. By imperfect combustion, the carburetted hydrogen distilled from fresh coal gives up the greater part of its hydrogen, and a solid carbonaceous residue is left; and this results either from excessive cooling, from a limited supply of air, or from imperfect mixing. In hand firing, the following difficulties are obvious: 1st, excessive cooling when the doors are opened for fresh coal; 2d, an excessive formation of combustible gases, immediately after, with deficiency of air supply; and 3d, an excessive air supply during the last stage of combustion, especially when the doors are opened to prepare for the next charge. It is instructive to watch the steam gauge of a boiler, when the stoker opens the fire-doors; and the advantage of mechanical feeders is naturally suggested. These may supply the fuel in uniform quantities, without the necessity of opening fire-doors; a uniform quantity of gas is therefore constantly evolved, the demand for air is uniform, and only the amount utilized need be admitted.

To follow the history of invention, we must begin with the three forms of furnace introduced by James Watt, in 1785. The first was a base-burner—a large cylinder serving as a reservoir for the fuel. The gases

*Copies of a portion of this Act were distributed by the lecturer among members of the Department of Science and Arts, the City Council, and the Ladies' Society for the Promotion of City Cleanliness. The Smoke Ordinance subsequently passed by the City Council, is practically a reproduction of these sections of the Leeds Improvement Act of 1843.

distilled in this reservoir were compelled, by the draught, to pass downward through the incandescent fuel, and supplied with air for their complete combustion. In the second furnace, two flat grates were fired alternately, with a system of dampers, whereby the gases distilled from the green fuel were compelled to pass over the incandescent coals on the other grate. A broad plate was placed in front of the third furnace, upon which the freshly charged fuel was moderately heated, the more volatile gases passing over the fire towards the bridge; the latter was hollow, for the admission of air. In these furnaces, Watt introduced the principles and the main features of construction found in ninety per cent. of the smoke-preventing devices of the present day; and during the next fifty years, we discover no improvement upon these plans.

About 1840, however, two improvements were invented by C. Wye Williams and John Jukes. The former substituted for Watt's hollow or split bridge, a plate containing several hundred half-inch openings, thus subdividing the air into jets, and securing a more thorough admixture with the combustible gases. Jukes connected the grate bars in an endless chain, and gave them a slow motion to carry the fuel from front to rear, dropping the ash and clinker near the bridge. The fuel was fed from a hopper, its depth upon the grate being regulated by the sliding gate. Jukes' device has grown in favor, and thousands are in use to-day, after the practical tests of forty years. These are not all known by the name of Jukes, however, for modifications and refinements have been added from time to time, and each new stoker is known by the name of its modifier or improver. The endless chain grate being expensive to maintain, several inventors applied a gentle, undulating motion to the series of bars, by which the same result is accomplished; and to make room for ordinary fire-doors between the hopper and the grate, the former was placed at a higher level, and the fuel is thrown in above the door, in small quantities, by an adjustable feed-plate.

In a second class of smoke preventers, fuel is fed into a hopper as before, and then passed through a pair of crushing rollers, from which it is delivered to a pair of rapidly rotating horizontal disks with vertical radial ribs, which throw it into the furnace. Numerous ingenious devices are employed for the purpose of obtaining an equal distribution of the fuel upon the surface of the grate. In one case, this is accomplished by driving the discs at a variable speed, the higher speed being calculated to supply the more distant, and the slower speed the nearer portions of the grate. The principal furnaces of this class are Butcher's (having the means for regulating the distribution just described), Henderson's, Smith's,

and Stanley's. Great numbers of each are in practical operation, and generally successful.

In the third class, the fuel is delivered from a hopper to the projecting ends of a series of horizontal conveyer screws, laid in troughs between the bars; and by means of these the fuel is gradually moved as it is consumed, from the fire-door to the bridge, where the ash and clinker remaining are pushed off the end of the bars and fall into the ash pit. In practice, these horizontal screw feeders introduce the fuel at the surface of the grate, so that the gases pass upward through the incandescent fuel. The feeder of M. Holyrood Smith is the principal one of this class, and comparatively few are in use.

Fourth Class.—The charge is introduced from below by means of a vertical screw, which raises the fuel from a circular pan in the ash-pit, or by a vertical plunger working in the ash-pit, which forces the coal up through a circular opening in the bars and under the incandescent fuel previously charged. But few of either description are in use.

Fifth Class.—The fuel is delivered from a hopper upon a plate or shelf at the furnace mouth, and is thrown from there by a shovel, operated by a spiral spring. The tension is put upon the spring by arms or lugs on a slowly rotating shaft, each of these arms being of different length, in order to vary the force with which the coal is projected, and thus secure its equal distribution within the furnace. This form of feeder is quite extensively used.

The foregoing is, in brief, the history of the successful smoke preventer, which led the Select Committee of the House of Commons to conclude that legislative interference in the matter of the smoke nuisance would impose no burden upon the manufacturer. It is the mechanical stoker that enables the English people to enforce the smoke sections of their Improvement Acts.

Factory furnaces, however, are not to be charged with all the smoke; if they were, English cities would be practically smokeless. The vast amount of coal consumed for domestic purposes, accounts for the only difficulty they encounter in clearing their atmosphere; for in London, smoke from factory chimneys is prevented, while from those of Paris, volumes of smoke, rivaling Cincinnati, are constantly emitted. Yet the London atmosphere is smoky, while that of Paris is clear. In London, vast quantities of bituminous coal are consumed for domestic purposes; in Paris, none. We must, therefore, conclude, that the difference in the atmosphere of the two capitals is due to a difference in domestic conditions.

The knowledge that these small fires are the cause of the trouble in London, has resulted in the invention of numerous devices for smokeless heating and cooking in the family. In some of these, a grate is filled with coke, lump fire-clay, or a mixture of lump and fibrous asbestos. The bottom rail of the grate is formed by a gas tube, perforated next to the material named. Upon lighting the gas, the flame ascends and surrounds the asbestos or other material, and it soon becomes incandescent, while the flame from the gas makes quite a cheerful fire, like the French gas fire-log.

Another device, "Bateman's Metal Fire," consists of a small circular cast iron base or box, containing a large vertical pipe, into the bottom of which is introduced a gas jet. The ascending heated column, arising through the tube from this jet when burning, together with the pressure of the gas, induces a current of air, which passes with the gas into a mixing chamber on top, where combustion takes place, producing a clear blue flame and heating a confused mass of wire above, which furnishes the heat-absorbing and radiating surface. To obtain satisfactory results from these devices, requires a consumption of from twenty to twenty-five feet of gas per hour. The cost of gas being $1.75 per thousand, a single fire would cost seventy cents per day of sixteen hours. It is unnecessary to add that excessive cost places these gas fires beyond the reach of the poor. The "National Health Society," of Great Britain, becoming aroused to the injurious effects of London smoke, appointed a committee in May, 1880, to investigate the subject. Examination led to the conclusion, that for factory furnaces, the devices employed left but little to be desired; but that for domestic use, while there were numerous competitors for popular favor, an uncertainty in the public mind as to their relative merits prevented their general adoption. It was decided, therefore, to arouse public interest in the matter, by holding public meetings, at which the necessary discussion could take place, and to hold an International Exhibition of Smoke Preventing Devices at South Kensington. [This exhibition has since been held, and it will doubtless add materially to our knowledge of the subject.]

XII. DANKS'S MECHANICAL STOKER.

By J. G. Danks.

[Read before the Section of Mechanics and Engineering, Dec. 15, 1881.]

It will be admitted by all that the firing of steam boilers is one of the most important operations connected with the manufacturing industries

of the country; and yet, unfortunately, it is one of the most neglected. The aim should be, not only to produce the greatest possible amount of steam with the least fuel, but also to protect the boiler itself from injury. Sudden changes of temperature, which cause sudden expansion and contraction, must be avoided; and I venture to say that more than one-half of the repairs on steam boilers to-day is necessitated by the strong local heat just over the fire, and at the bridge wall, which is sometimes built up to within three or four inches of the boiler. The first two sheets immediately over the fire often have to be patched or replaced by new ones, because the lap and rivet heads are burned off and the plate is cracked from one to three inches back of each rivet-hole. In cases where dirty water is used, I have seen new plates badly burned from this cause in one week.

In applying the Danks Mechanical Stoker to steam boilers, it has been the aim to avoid, as far as may be, the objections and dangers attending the usual method. The grate, instead of being directly beneath the boiler, is arranged somewhat in front of it, in a combustion chamber of refractory firebrick, in which the gases of combustion are produced, heated, and ignited, before coming into contact with the boiler. By these means we may avoid not only the imperfect combustion of the fuel, resulting from the cooling of the gases below the proper point of ignition, but also the intense local heat, which is so injurious when the bottom of the boiler forms the roof of the furnace.

The grate bars are in two sets. The short vertical bars in front (about twelve inches in height) are hinged at the bottom in such a manner that they may be raised or lowered at pleasure, making a convenient opening through which to start the fires; and by the additional grate surface obtained in this way, the horizontal bars may be made so short (say three feet) that they may be kept covered automatically.

The stoking apparatus proper* consists of a horizontal trough placed

*The use of a screw-feed is not uncommon in English inventions of an early date. So also as to the use of a "hanging bridge" or "reverberatory arch" of firebrick, patented in England by Chanter in 1834, Hopkins in 1836, Prosser in 1839, and described by Coombs in his patent of 1813, by Wakefield in 1820, and by others. The same idea is embodied in the "Murphy 'Smokeless Furnace,'" and many others in this country, and is undoubtedly based upon correct scientific principles. The eolipiles of the early Greeks and Romans show a familiarity with the uses of the air blast from ancient times; and as early as 1813 its use in modern furnaces of various kinds begins to appear in the English patents, both in the natural state and heated. Mr. Danks' device was patented June 27, 1871, and is undoubtedly an excellent adaptation of well-known principles in an economical and practical form.—L. M. H.

transversely in front of the boilers or battery of boilers, in which trough, a number of spiral conveyers, or "augers," are arranged to force the slack coal (with which the trough is kept charged) into the combustion chamber upon the grates. These augers are made of cast iron, about six inches in diameter, with four inches pitch of screw. They are placed about fifteen inches from center to center, and are operated by ratchet wheels and a system of concentric pawls upon a reciprocating parallel rod, driven by suitable connections with the mill machinery, or by independent power.

The device is most profitably employed with common slack coal, in connection with a forced blast of air, usually driven by an ordinary fan-blower. In such case, with suitable means for regulating and adjusting the quantity of fuel fed to the grates, the operation may go on for hours without disturbing the fire, except to break up the cinders occasionally to maintain a free passage for the blast.

In this mode of firing, the fresh coal is always forced into the grate *under* a surface of incandescent fuel. The gases distilled from the coal must pass through this, and become thoroughly heated; and before they are allowed to pass under the boiler, they are met and thoroughly mixed with the proper amount of oxygen, which is admitted through perforated bricks in the furnace roof.

The under side of the furnace roof is brought down about twelve inches below the bottom of the boiler; not only to give access to the hand-holeplate flues, but also to give the gases a downward motion, and to keep them from striking the bottom of the boiler until they have expanded in the large chamber provided for their combustion.

The advantages of the mechanical stoker are many. It seems to effect a saving of fuel amounting to about 25 per cent. It avoids the necessity of opening fire doors, with the consequent sudden cooling of the furnace and boiler. The supply of fuel is constant, which is a great advantage over hand-firing, in the prevention of smoke as well as economy; for where is the fireman who will not take advantage of an opportunity to throw on a large quantity of coal at one time, in order that he may have a rest, although this is totally at variance with the principles of rational firing?

I do not hesitate to say, that when the question of preventing smoke is satisfactorily solved, it will be by a mechanical stoker.

XIII.—TRIAL OF A SLIDE VALVE STEAM ENGINE.

By J. C. Hoadley, M. E.

[Report of expert tests made at the Cincinnati Industrial Exposition of 1881. Compare editorial note on page 54.]

The award of this premium to Entry No. 18, Atlas Engine Works, was based on very thorough examination and test of its performance in driving machines for electric lighting—a class in which it was not entered for competition, but in which all its work was done during the Exposition. Diagrams were taken from it:

1. When driving the line of shafting overhead, about $2\frac{15}{16}$ in. diameter, and about 60 ft. long, at about 400 revolutions per minute, together with the shafts of 2 Weston 10, 1,000-candle arc light machines, and 1 Maxim, 40, 25-candle incandescent light machine, without currents, and therefore with no load but the frictions of the engine, line shaft and electric machine shafts, giving 11·99 I. H. P.

2. With 1 Maxim 40, 25-candle incandescent light machine, with 34 lights burning, and no more. This gave 19·45 I. H. P.

3. With the same, 40 lights burning, giving 20·26 I. H. P.

4. With the same, 40 lights and 2 Weston, 10, 1,000-candle arc light machines, all burning, giving 43·82 I. H. P.

5. The 2 Weston Machines, all lights burning, and the current thrown off from the Maxim, giving 34·99 I. H. P.

Combining these numbers, we obtain:

1 Maxim, 40, 25-candle incandescent light machine, all burning—

$$43{\cdot}82-34{\cdot}99=8{\cdot}83$$
$$20{\cdot}26-11{\cdot}99=8{\cdot}27$$
$$\text{Mean } \frac{8{\cdot}83+8{\cdot}27}{2}=8{\cdot}55$$

1 Maxim, 40, 25-candle incandescent light machine, 34 lights burning—

$$19{\cdot}45-11{\cdot}99=7{\cdot}46$$
$$\frac{8{\cdot}83}{40}={\cdot}221 \qquad \frac{8{\cdot}27}{40}={\cdot}207 \qquad \frac{8{\cdot}55}{40}={\cdot}214 \qquad \frac{7{\cdot}46}{34}={\cdot}220$$

2 Weston, 10, 1,000-candle arc light machines, all burning—

$$34{\cdot}99-11{\cdot}99=23{\cdot}00$$
$$43{\cdot}82-20{\cdot}26=23{\cdot}56$$
$$\frac{23{\cdot}56+23{\cdot}00}{2}=23{\cdot}28$$

1 Weston, 10, 1,000-candle arc light machine—

$$\frac{23{\cdot}28}{2}=11{\cdot}64$$

$$\frac{23{\cdot}00}{20}=1{\cdot}15 \qquad \frac{23{\cdot}56}{20}=1{\cdot}178 \qquad \frac{23{\cdot}28}{20}=1{\cdot}164 \qquad \frac{11{\cdot}64}{10}=1{\cdot}164$$

These results are satisfactorily consistent, and mutually confirmatory.

The speed of the engine, as counted when the diagrams were taken, was:

With 43·82 I. H. P.	....	221·5	Revolutions	per minute.
" 34·99 "	....	222·	"	"
" 20·26 "	....	225·	"	"
" 19·45 "	....	225·	"	"

A diminution of 44·4 per cent. in the power, attended by an increase of speed of only 1·56 per cent. Other observations gave similar results.

This engine was—10 in. cylinder, 20 in. stroke, piston rod 1$\frac{11}{16}$ in. diameter.

Area of large side of piston.....sq. in.	78·54
Area of small side..... "	76·30
Mean net area of piston..... "	77·42
Volume swept through by piston, large side.....cub. in.	1570·8
Volume swept through by piston, small side..... "	1526·0
Volume swept through per revolution.....cub. ft.	1·7921759
Clearance and waste—room at each end, if evenly divided, cub. in.	114·5
Length of clearance, in terms of stroke; end of cylinder nearest to crank.....	·07503
Length of clearance, in terms of stroke; end of cylinder farthest from crank.....	·07289
Length of clearance, in terms of stroke; mean.....	·07421
Cut-off, at crank end, at part of stroke.....	·8125
Cut off, out end, at part of stroke.....	·6875
Outside lap of valve.....in.	·875
Inside lap of valve.....(?) in.	·5
Exhaust lead.....in.	·375
Travel of valve.....in.	3·5
Steam pores.....in.	0·75×8·
Exhaust pores.....in.	2·00×8·
Bridge.....in.	·875
Length of valve over all.....in.	7·
Width of D.....in.	2·75

The subjoined diagram is one of those above referred to, and represents 20·15 lbs. mean effective pressure, at 222 revolutions per minute, producing 34·94 I. H. P.

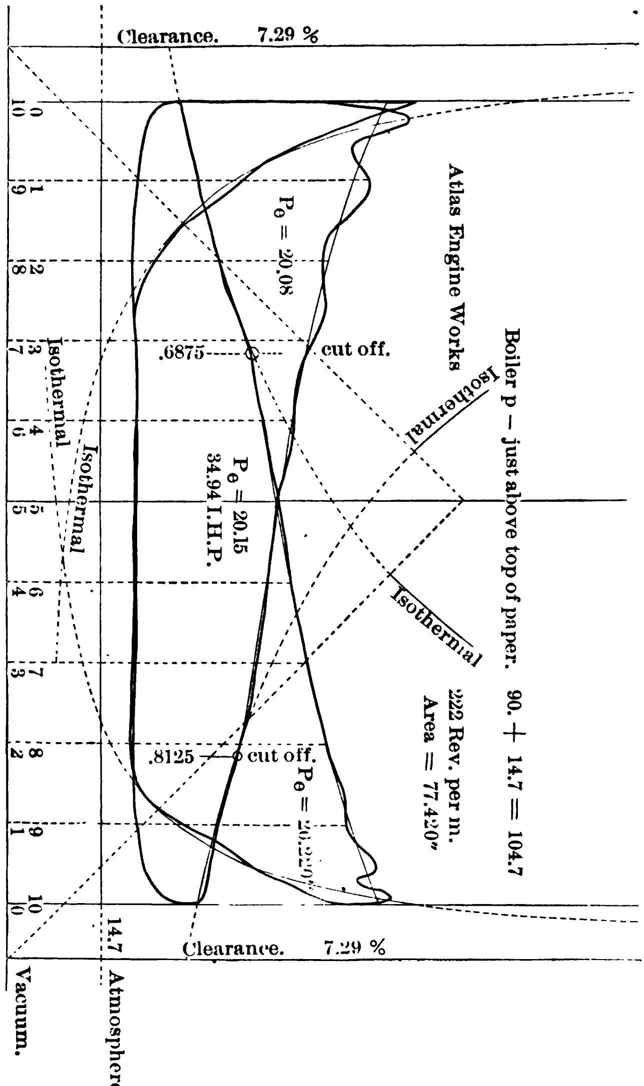

Clearance. 7.29 %
Atlas Engine Works
Boiler p – just above top of paper. 90. + 14.7 = 104.7
222 Rev. per m.
Area = 77.420"
Isothermal
Isothermal
Isothermal
Isothermal
.6875
cut off.
.8125
cut off.
Pe = 20.08
Pe = 20.15
34.94 I.H.P.
Clearance. 7.29 %
14.7
Atmosphere.
Vacuum.

Diagram No. 1.

XIV—TRIAL OF QUICK-ACTING STEAM ENGINES, FOR ELECTRIC LIGHT.

BY J. C. HOADLEY, M. E.

[Report of expert tests made at the Cincinnati Industrial Exposition of 1881. Compare editorial note on page 54.]

THE subjoined table (page 125), prepared and arranged by Mr. Walter Laidlaw, from numerous and patient observations made chiefly by himself and Professor R. B. Warder, shows clearly the relative merits of the five engines which it was possible to test, with respect to a single quality, quite indispensable in any engine for electric lighting, the quality, namely, of nearly uniform rotary velocity under varying conditions of load, thrown on and off suddenly. However desirable other qualities may be in these engines, in common with all other steam engines, this quality of steadiness of motion so far transcends all others for this especial purpose, that some degree of any or all other qualities might be judiciously sacrificed if necessary to its attainment.

The relative rank of the five engines tested, by counting the number of revolutions they made per minute, or per half minute, with load and without, the whole load being alternately thrown on and off by making and breaking the circuit, will be found in the table, in much detail, although the figures are the results or means of great numbers of observations of each engine.

The grand means of all the observations in each case, by a comparison of which the relative rank of each engine is determined, are as affixed to the designation of the respective engines, as follows:

VARIATIONS OF SPEED FROM LIGHT TO FULL LOAD.

Huber Manufacturing Co.	1·213	per cent.
New York Safety Steam Power Co.	2·188	"
Miner Duplex	2·939	"
M. Ruthenburg & Co.	9·52	"
Atlas Engine Works	11·772	"

This table requires neither explanation nor qualification. The engine standing at the head has but 55·5 per cent. as much variation as the one next to it, 41·3 per cent. of that of the third, 12·7 per cent. of that of the fourth, and, finally, only 10·3 per cent., barely over one-tenth as much variation as the Atlas "Square Engine."

Something should be said, however, respecting the other qualities and the general character of each of these exhibits.

TABLE.—VARIATIONS IN SPEED UNDER VARYING LOAD.

	"MINER" 2 cyl. 7″x7″ driving 1 Maxim Machine, giving 40 20-candle power lights, consuming 8·55 H.P.	"HUBER" 7½x8″ stroke driving 1 Maxim Machine of 8,000 candles, consuming 7 H.P.	'NEW YORK SAFETY' driving 1 Maxim Machine of 8,000 candles, consuming 7 H.P.	"RUTHENBURG" 2 cyl. 7″x7″, driving 2 Weston Machines of 10,000 candles consuming 23 H.P.	"ATLAS" SQ. ENGINE 1 cyl., 7″x7″, driving one Maxim Machine of 8,000 candles, consuming 7 H.P.
4TH OCTOBER, 1881.					
Rev's. per minute, with steady load, 1 minute observations	391.8				
Rev's. per minute, with no load, 1 minute observations	404.25				
Difference in speed	3.17%				
Rev's. per minute, when load is suddenly thrown on	393.25				
Loss in speed	2.73%				
Rev's. per minute, when load is suddenly thrown off	405.25				
Gain in speed	3.64%				
Rev's. per ½ minute, with steady load, ½ minute observations	195.9				
Rev's per ½ minute, with no load	202.125				
Difference in speed	3.17%				
Rev's. per ½ minute, when load is suddenly thrown on	195.5				
Loss in speed	3.28%				
Rev's. per ½ minute, when load is suddenly thrown off	203.00				
Increase in speed	3.624%				
5TH OCTOBER.					
Rev's. per minute, with steady load, 1 minute observations	397.375	291.66	175.43	361.00	220.
Rev's. per minute, with no load	406.75	294.6	179.33	394.00	243.4
Difference in speed	2.359%	1.00%	2.22%	9.14%	10.636%
Rev's. per minute, when load is suddenly thrown on	397.33	292.0	175.4	358.75	223.5
Loss in speed	2.32%	0.883%	2.2%	9.00%	8.18%
Rev's. per minute, when load is suddenly thrown off	407.75	297.66	180.2	400.25	256.5
Increase in speed	2.585%	2.05%	2.71%	10.87%	16.5%
Rev's. per ½ minute, with steady load ½ minute observations	198.687	145.83	87.71	180.5	
Rev's. per ½ minute, without load, ½ minute observations	203.375	147.3	89.66	197.0	
Difference in speed	2.359%	1.00%	2.22%	9.14%	
Rev's. per ½ minute, when load is suddenly thrown on	195.5	144.5	86.66	181.00	
Loss in speed	3.88%	1.1%	3.35%	8.18%	
Rev's. per ½ minute, when load is suddenly thrown off	203.00	147.66	87.33	200.00	
Increase in speed	2.17%	1.25%	0.44%	10.80%	
Grand mean of all the variations in speed	2.939%	1.213%	2.188%	9.52%	11.772%

THE MINER DUPLEX ENGINE.

This singular and not unattractive machine is a two-cylinder engine, 7 in. diameter, 7 in. stroke, set "quartering"; but instead of taking hold of two cranks at right angles, on the same shaft, the connecting rods take hold of the extremities of the horizontal arms of a cruciform walking-beam, the upper arm of which is guided and controlled by a rocker articulated to the frame, while the lower arm turns the crank.

The plain slide valves (in a measure relieved of pressure, it is said, by cutting about half the valve-seat into channels) are moved by one eccentric through a similar walking-beam. The engine is upright, with the cylinders aloft; is neatly proportioned and well made, and attracts the eye as often as one passes it. Without geometrical analysis, and in the absence of diagrams, I was in doubt whether its ultimate action was exactly like that of a two-cylinder engine coupled in the usual manner; or if, as seemed most likely, this action were in some slight degree modified. I was still more in doubt whether such modification was likely to be for the better or for the worse. On applying an indicator, the diagrams, of which a number were taken, all having the same general characteristics as the one herewith, showed that the valve motion, at both opening and closing, is very tardy and slow. In about the same degree that the Corliss wrist-plate accelerates the opening and closing, this device retards both these events.

The card shows late admission, tardy supply; the cylinder, of course, being completely filled with steam of maximum pressure up to the point where maximum pressure is attained; almost full stroke admission, very tardy and slow release, and very slight compression. With 52·5 lbs. pressure in the steam-pipe, and only one or two pounds back pressure besides what is caused by the valves of the engine—speed 212 revolutions per minute—the mean effective pressure for both strokes was 34·5 lbs. per square inch; the power, in one cylinder, 9·83 I. H. P.; and the steam expended, per I. H. P. per hour, 44·62 lbs. Both ends of this cylinder are doing about alike, and if the other cylinder is doing similarly (of which there can be no knowledge without applying an indicator to that also), the power of both is 19·66 I. H. P., the total expenditure of steam 877·2 lbs. per hour, and, as before, 44·62 lbs. per hour for each I. H. P. It is possible to do worse than this, but not much worse.

THE MARCUS RUTHENBURG & CO. ENGINE.

This pretty machine attracted much favorable notice by the symmetry of its design and the high speed at which it was sometimes allowed to run.

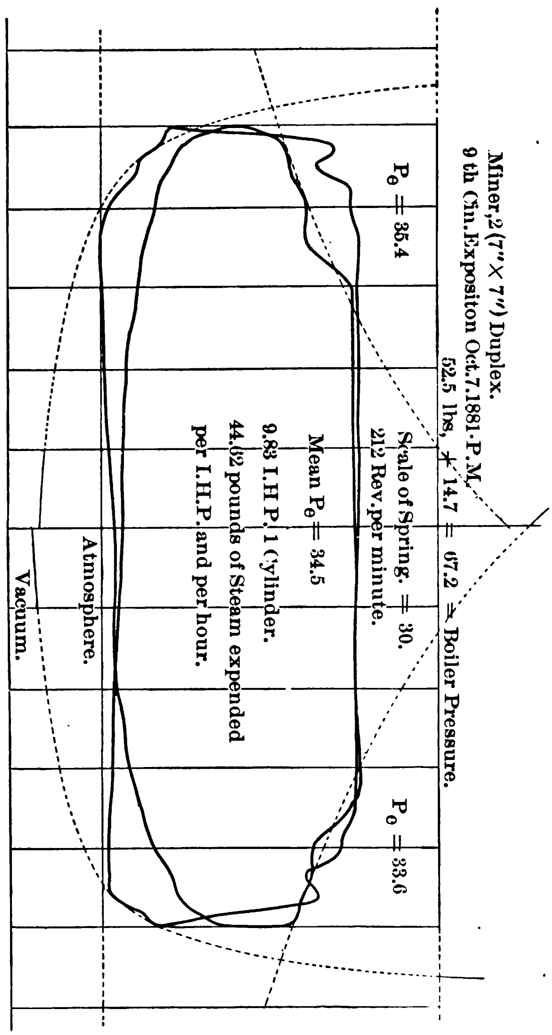

Miner,2(7"×7") Duplex.
9 th Cin.Expositon Oct.7.1881·P.M.
52.5 lbs, + 14.7 = 67.2 = Boiler Pressure.
Scale of Spring. = 30.
212 Rev.per minute.
Mean P_e = 34.5
9.83 I.H.P. 1 Cylinder.
44.62 pounds of Steam expended
per I.H.P. and per hour.
P_e = 35.4
P_e = 33.6
Atmosphere.
Vacuum.

Diagram No. 2.

The diagram herewith, one of several all substantially alike in character, shows it to be a full-stroke engine at one end and nearly so at the other. Compression is very good; all the other events are about dead-center events. With steam at 70 lbs. gauge pressure, speed 443 revolutions per minute, piston speed 516·83 ft. per minute, the mean effective pressure, both strokes, is 21·63 lbs. the power, for one cylinder, 12·873 I. H. P., and the steam expended per hour, 664·05 lbs. for one cylinder, and for the two cylinders—if working alike—1328·1 lbs., equal to 51·58 lbs. of steam expended every hour for each one horse power indicated. It would not be easy to get more steam than this through the ports of any cylinder of the size of these without leakage.

As a winding engine, if fuel were of no consequence, the engine is very suitable. It was made, it is said, from the first conception, to setting up and starting, in 22 working days, and started up without delay.

NEW YORK SAFETY STEAM POWER CO. ENGINE.

This is one of the handsome vertical engines so well and widely known as the manufacture of this company.

No cards were taken from it, as no provision was made for applying an indicator. The lines it makes are well known; something, in general character, like the diagram below, from the Atlas "Square Engine." In steadiness of motion it was found to be second to the Huber; but then the Huber has an automatic cut-off, governing the speed by controlling both suppression and release.

THE HUBER ENGINE.

This is just such an engine, mounted on just such a boiler, as will be found fully described in the account of the Huber Combined Traction and Farm Engine (p. 65) except—a momentous exception—the governor, which in this engine is automatic, controlling the valve (an ordinary slide valve) by direct action on the eccentric. Very unattractive when not in action, this engine fascinated the eye of every competent mechanic who witnessed its operation. It was submitted to the severest tests, a load of 10 to 12 horse power being alternately thrown on and off in an instant, by making and breaking circuit, with very slight disturbance of the uniformity of its motion. By no means well built, and capable of great improvement of detail, this Huber Portable Engine is the only one among the seven exhibited suitable to drive Dynamo Electric Machines for electric lighting, as it is the only one capable of sufficient nicety of regulation, and is entitled to the award.

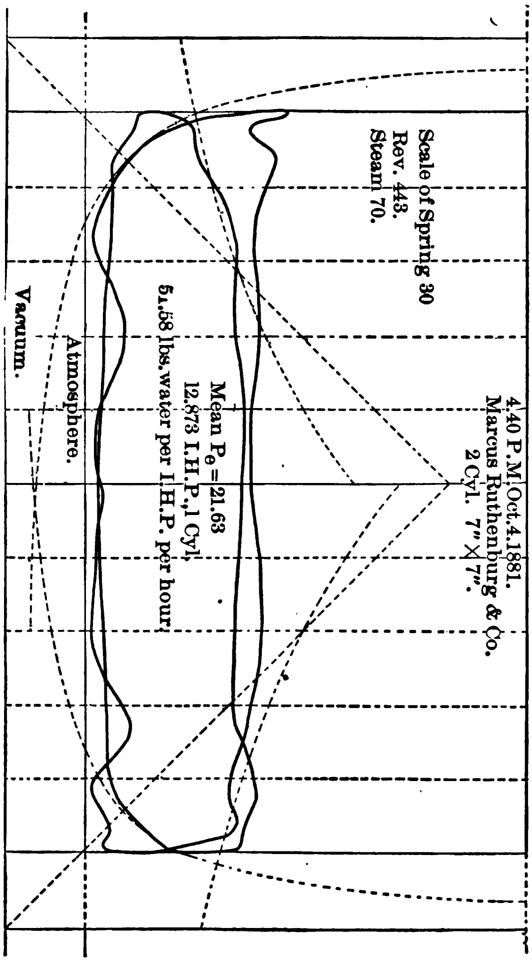

Scale of Spring 30
Rev. 443.
Steam 70.
4.40 P.M. Oct. 4. 1881.
Marcus Ruthenburg & Co.
2 Cyl. 7" X 7".
Mean P_e = 21.63
12.873 I.H.P., 1 Cyl.
51.58 lbs. water per I.H.P. per hour.
Atmosphere.
Vacuum.

Diagram No. 3.

No diagrams were taken from it. They must be very much like link motion, locomotive diagrams, with variable cut-off and exhaust closure.

ATLAS "SQUARE ENGINE."

A pair of diagrams from this engine is given below. It is one of several taken with varying pressure, all similar in character, and there are some almost indistinguishable from this. The pressure is low, the power small, and the quantity of steam expended per I. H. P. in an hour is large, 46·35 lbs. The cards are remarkably near alike at the two ends of the cylinder, and with higher pressure would be pretty good. But that's the rub: with a throttling governor it is impossible to get high pressure into the cylinder, at normal speeds, however high the boiler pressure may be. Clearance, assumed in the diagrams to be 10 per cent., may be more or less, but is probably about that. The expansion lines are a little higher at the lower end than the isothermal curve, as is to be expected. The isothermal curves of compression are probably about right. I do not know what, in this instance, causes the extension of the diagrams at the upper part beyond these isothermal curves; but when I found it in my own engine, I always learned, on examination, that it was caused by leakage at the piston.

The diagrams of these quick-running engines were, for the most part, taken by Mr. Frank Lederle, with a Tabor Indicator.

XV.—CONTAMINATION OF MAPLE SIRUP FROM EVAPORATION IN GALVANIZED IRON.

BY R. B. WARDER.

[Read before the Section of Chemistry and Physics, March 23, as the Report of a Special Committee, appointed February 23, 1882. See pages 51, 53.]

AT the February meeting of this Section, information was received from Mr. Stanley Hatch, of Riverside, that some maple sirup, which had been made in a pan of galvanized iron, had an unpleasant taste. This led to a suspicion of contamination with zinc. The committee appointed to examine this matter submit the following report:

Mr. Hatch furnished us with samples of fresh maple sap, and of the sirup made in the first run. He informs us that the evaporating pan of galvanized iron was made by a tinner, with rivet heads on the outside and soldered perfectly tight. It was cleansed before using. The sap was

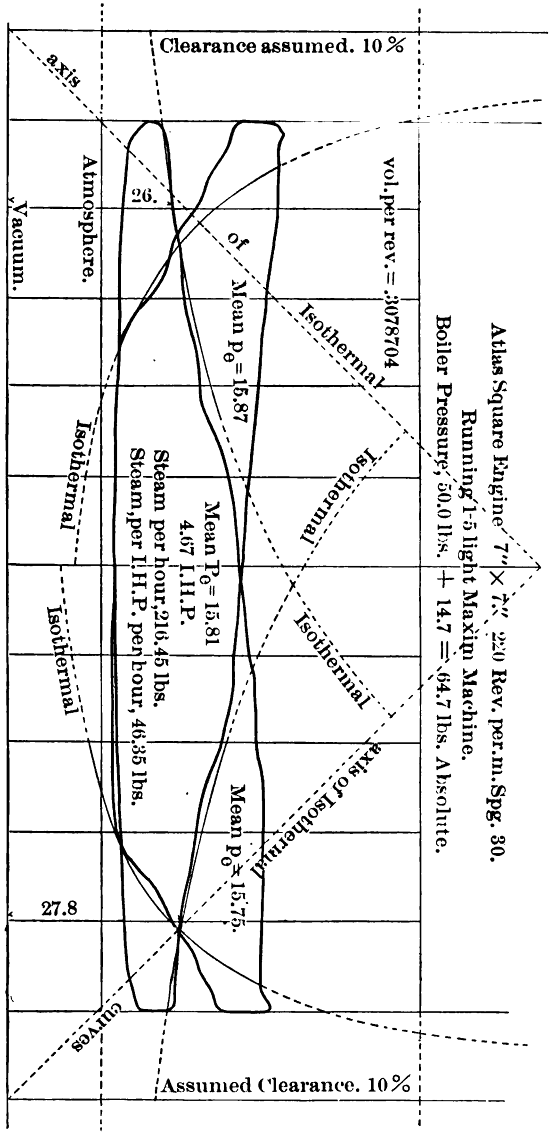

Clearance assumed. 10 %
axis
of
Isothermal
Atmosphere.
Vacuum.
26.
vol. per rev. = .3078704
Mean p_e = 15.87
Atlas Square Engine 7" × 7" 220 Rev. per.m. Spg. 30.
Running 1-5 light Maxim Machine.
Boiler Pressure, 50.0 lbs. + 14.7 = 64.7 lbs. Absolute.
Isothermal
Isothermal
Mean p_e = 15.81
4.67 I.H.P.
Steam per hour, 216.45 lbs.
Steam, per I.H.P. per hour, 46.35 lbs.
Isothermal
Isothermal
axis of Isothermal
curves
Mean p_e = 15.75.
27.8
Assumed Clearance. 10 %

Diagram No. 4.

first put into barrels which had been used for wine and cider; and, although these had been carefully cleansed, the sap may have begun to ferment or sour, during an interval of two or three days, before evaporation. The zinc coating remained upon the pan, but lost its brightness.

We have been unable to learn of any direct experiments to determine whether maple sap and sirup at the boiling temperature will or will not act upon the surface of galvanized iron. We submit, therefore, such indirect evidence as we have been able to gather, with the results of our own chemical examination. Any fuller investigation must be deferred until another season.

The so-called "galvanized iron" consists essentially of sheet iron coated on both sides with zinc. A film of tin is sometimes deposited upon the iron first, in order to secure a more perfect adhesion of the zinc; but no danger was apprehended, except from the zinc itself. The pans are usually soldered so that no edges of iron are exposed; but the solder itself renders the surface non-homogeneous, and may thus promote galvanic action and corrosion. Manufacturers and dealers in sugar-making apparatus inform us that galvanized iron evaporating pans were introduced about the year 1859, and that they are now in general use, no complaints of corrosion or zinc poisoning having come to their notice. This material is much preferred to sheet iron, which rusts (if not painted) during the long interval from one season of use to another. Mr. C. G. Hampton, of Detroit, Michigan, informs us that galvanized iron is nearly always used for the evaporation of maple sap, except when the same pan is also to serve for the concentration of apple juice; in this case, copper pans are used. It is stated that galvanized iron will do service for ten seasons, and that the zinc coating is not worn through, unless by excessive scouring.

Prof. H. A. Weber, of Champaign, Illinois, has given us the following statement: "The material generally used here for evaporating pans is galvanized iron. The normal condition of sorghum juice is acid. The zinc coating is dissolved off very soon when the juice is not neutralized."

A sample of galvanized iron, kindly furnished by the Blymyer Manufacturing Company, was found to weigh 51·6 grams to the square decimeter, including 18 per cent. of zinc. There were, therefore, 4·64 grams of zinc on either side, to one square decimeter of sheet-metal. Now, it is estimated that 0·8 liter of sirup can be obtained by the evaporation of medium cane juice, per square decimeter of evaporating surface, per day of 12 hours. The maple sap, being much more dilate, we may estimate at least 0·2 liter of maple sirup per square decimeter, per day, or 120

liters of sirup during ten seasons of 60 days each. If we should suppose that by gradual chemical action the whole quantity of zinc, from the inside surface, is dissolved off and uniformly distributed through this quantity of sirup, allowing 1·5 square decimeters of metal to 1 square decimeter of evaporating surface, we would have $\frac{1}{120} \times 1·5 \times 4·64$ grams $=$ 58 milligrams of zinc to each liter of sirup. The amount actually dissolved, under ordinary conditions, must be decidedly less than this. 58 milligrams of zinc would correspond to 256 milligrams (or 3·4 grains) of crystallized zinc sulphate. Since this salt is prescribed as a tonic, in doses of one or two grains, the maximum quantity of zinc that could go into solution under ordinary conditions will hardly be considered a source of danger, even if a liter of sirup is consumed by an individual in a single week.

The following facts from published investigations have a bearing on the present subject. A. Wagner* studied the action of various solutions upon iron, copper, zinc, lead, tin, and alloys. He found that the addition of salts or caustic soda usually increases the action; but lime and (to some extent) sodic carbonate diminish the action upon zinc. There is a remarkable difference in the behavior of zinc and lead towards alkaline solutions.

Snyders† investigated the chemical action of water and saline solutions upon zinc for moderate temperatures, with remarkable thoroughness. He showed that with water from which oxygen and carbonic acid were carefully excluded, no action could be detected by the most delicate reagents; but in presence of oxygen, traces of zinc are dissolved by distilled water, as hydrate. Most salts (especially chlorides and ammonium salts) increase the solvent action of water very much. In the absence of oxygen, water may even be decomposed by the united action of zinc and common salt, while the solution becomes alkaline, and hydrogen is set free. This is probably due to the formation of the double salt, thus:

$$Zn + 4\,Na\,Cl + 2\,H_2\,O = Zn\,Cl_2\,2\,Na\,Cl + 2\,Na\,OH + H_2.$$

Alkaline carbonates and phosphates tend to limit the action by forming an insoluble coating on the surface of the zinc. If Snyders had extended his investigation to saccharine liquids, and especially if he had made his experiments at high temperatures, they would be more directly applicable to the problem in hand; but the work which he did will be of service to us.

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* Dingl. polyt. Jour., **218**, 70, and **221**, 259; or, Jahresb. d. Chem., 1875, 208, and 1876, 217.

† Ber. d. chem. Gesel., **11**, 936; Jahresb. d. chem., 1878, 1108.

Our own analyses of the samples received from Mr. Hatch led to the following results. The sap when examined had distinct acid reaction. By titration with caustic soda and phenol phthalein (with prolonged boiling to expel CO_2) we found that a liter of the sap would neutralize 28 milligrams Na OH, corresponding to 42 milligrams acetic acid. The sirup was rich and viscous, of dark color, having a specific gravity of 1·732 at 22° C., having the characteristic maple taste, but leaving an unpleasant astringent after taste, similar to that of zinc salts, yet not so pronounced as to render the sirup wholly unpalatable. This also had acid reaction; and titration indicated 300 milligrams (calculated as acetic acid) to 1 K. It gave 1·38 per cent. of white ash. We may readily see from the experiments of Wagner and Snyders that such acid liquids, especially at high temperatures, could not fail to have an appreciable action upon the zinc. The presence of this metal in the sirup was clearly shown by qualitative tests, both wet and dry. Unfortunately, the material at our disposal was not sufficient for the accurate estimation of zinc; but a single determination gave us about 0·1 per cent. of Zn O. This amount, calculated as sulphate, would correspond to 6·14 grams (95 grains) of the crystallized salt per liter. Such an amount must certainly be regarded as unwholesome; though perhaps not dangerous, if the sirup is used in moderation.

Conclusions.

1. Galvanized iron evaporating pans have been used in sugar-making (including maple sugar) for more than twenty years. This material seems to be generally preferred to any other.

2. Even pure water, in presence of air, is known to have a distinct solvent action upon zinc, at the ordinary temperature. This action would doubtless be much increased, in the evaporation of sap, in consequence of the high temperature, and the salts found in the sap.

3. In ordinary cases, this action is practically so slight that the zinc dissolved can not be considered a source of danger. If the sap is allowed to become sour, however, the sirup may take up so much zinc as to become unsalable and unwholesome, even if not absolutely dangerous.

4. The danger of contamination may be diminished by promptly evaporating the sap, before fermentation or souring begins to take place. Addition of a little lime, or other alkali, may sometimes be helpful even for maple sap.

5. When the pan is new, it may also be desirable to form an insoluble film over this surface by first boiling a solution of sodic phosphate, or even hard spring water, to diminish the action of the sap or cane juice.

XVI.—GHOSTS, BY REFLECTION IN THE OBJECTIVE OF A REFRACTING TELESCOPE.

BY R. B. WARDER.

[Read before the Section of Chemistry and Physics, February 23, 1882.]

WHEN a ray of light passes through a lens or similar transparent body, a portion is reflected back from the second surface upon the first; a part of this is reflected forward again from the first surface; and thus a faint secondary image, called a ghost, may be projected, in addition to the primary image. Ghosts of higher order may be formed in like manner, by four or more reflections; but the quantity of light very rapidly diminishes. In a system of lenses, since a real or virtual secondary image may be caused by reflection from any two surfaces, $\frac{1}{2} n (n-1)$ will be the maximum number of ghosts of the first order possible, where n is the total number of refracting and reflecting surfaces. Thus, a combination of two lenses may give rise to six ghosts, while four lenses may produce twenty-eight ghosts of the first order. In practice, however, the great majority of these are unseen and do not impair the definition of the primary image, which the instrument is designed to show.

The ghosts projected by reflection in the eye-piece are well known, and are often seen as faint companions to the principal image. These may generally be easily distinguished by their change of position when the direction of the telescope is altered; and yet eminent observers have sometimes been misled by this phenomenon.* The ghosts arising from reflections in the object glass, on the other hand, will generally be at some distance from the focal plane, and therefore can not be seen directly when the eye-piece is focussed upon the primary image. If the ghost is quite near the focal plane, however, the field of view surrounding the image is more or less illuminated by the cone of extraneous rays belonging to the ghost. It is therefore desirable to select such a form for the objective that the nearest ghost shall be far enough from the focal plane to insure practical freedom from this defect. The ghosts resulting from reflection between the eye-piece and the objective have probably never been a source of inconvenience; and yet this case might arise if the posterior face of the objective should be concave, with a radius of curvature nearly equal to the focal length of the telescope.

* A good illustration is the announcement, in 1846, that "Antares is triplex." The error was pointed out by Professor Mitchell, in *Siderial Messenger*, vol. I., pp. 48–50.

POSITION OF THE GHOST.

When the axis of a telescope is directed toward a star, the pencil of light falling upon each surface of a lens will be partly refracted and partly reflected; the resulting beam in each case will have a real or virtual

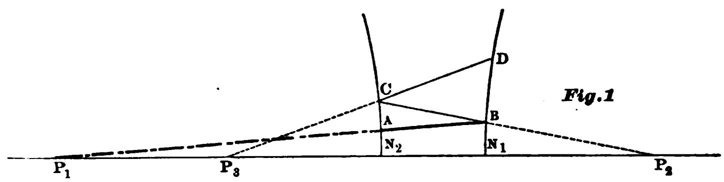


Fig.1

vertex in the axis of the telescope. Let N_1, N_2 (Fig. 1) be any two successive surfaces, reflecting part of the ray AB to C and to D. Prolong each portion of the broken ray, intersecting the axis at P_1, P_2 and P_3. Then P_1 is the vertex of the original pencil, as it emerges from N_2; P_2 is the vertex of the rays after one reflection; and P_3 is the vertex of the pencil that has suffered two reflections and produces the ghost. If the curvatures and distance of N_1 and N_2 should be so adjusted as to make P_3 coincide with P_1, the ghost will coincide with the primary image, and will therefore be indistinguishable; but the further P_3 is removed from P_1, the further will the ghost be removed from the focal plane.

Let p and p', with appropriate subscripts, denote the conjugate focal distances by reflection, while p'' denotes the distance of an image formed by refraction. The position of each ghost may then be determined by the successive application of the formulæ of elementary optics,

$$p' = \frac{pr}{2p - r} \text{ (1) and } p'' = \frac{pf}{p - f} \text{ (2).}$$

Similar notation is used in the several figures, where (neglecting the thickness of the lenses)—

$$\begin{array}{lll} P_1 N_1 = p_1 & P_2 N_1 = p'_1 & N_1 P_4 = p''_1 \\ N_2 P_2 = p_2 & N_2 P_3 = p'_2 & \\ P_3 N_1 = p_3 & & N_1 P_5 = p''_3 \end{array}$$

Also, let $N_2 N_1 = d$

radius of curvature of $N_1 = r_1$

" " " " $N_2 = r_2$.

The rays of light are supposed to go from left to right, which is assumed to be the positive direction; and it must be carefully observed that the values of p, p', and r are negative when measured behind a reflecting surface; thus, in Fig. 1, p'_1 is the negative quantity $P_2 N_1 = -N_1 P_2$.

Since $N_2 P_2 = N_2 N_1 + N_1 P_2 = N_2 N_1 - P_2 N_1$,

$$p_2 = d - p'_1;$$

or, by eq. (1), $p_2 = d - \dfrac{p_1 r_1}{2 p_1 - r_1}$

$$\text{and } p'_2 = \frac{\left(d - \dfrac{p_1 r_1}{2 p_1 - r_1}\right) r_2}{2\left(d - \dfrac{p_1 r_1}{2 p_1 - r_1}\right) - r_2} = \frac{d\,(2 p_1 - r_1)\, r_2 - p_1 r_1 r_2}{2\, d\,(2 p_1 - r_1) - 2 p_1 (r_1 + r_2) + r_1 r_2} \qquad (3)$$

Two steps are now required to complete the problem; first, to find how far P_3 is removed from P_1; and, second, to determine how the dioptric image would be shifted by changing the vertex of a pencil from P_1 to P_3.

$$P_3 P_1 = P_3 N_2 + N_2 N_1 + N_1 P_1 = N_2 N_1 - P_1 N_1 - N_2 P_3 = d - p_1 - p'_2$$

$$\therefore\ P_3 P_1 = d - p_1 - \frac{d\,(2 p_1 - r_1)\, r_2 - p_1 r_1 r_2}{2\, d\,(2 p_1 - r_1) - 2 p_1 (r_1 + r_2) + r_1 r_2}$$

$$= \frac{d^2 (2 p_1 - r_1) - d\,(2 p_1^2 + 2 p_1 r_2 - r_1 r_2) + p_1^2 (r_1 + r_2)}{d\,(2 p_1 - r_1) - p_1 (r_1 + r_2) + \tfrac{1}{2} r_1 r_2} \qquad (4)$$

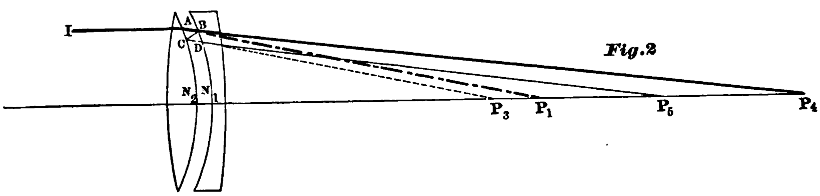


Fig.2

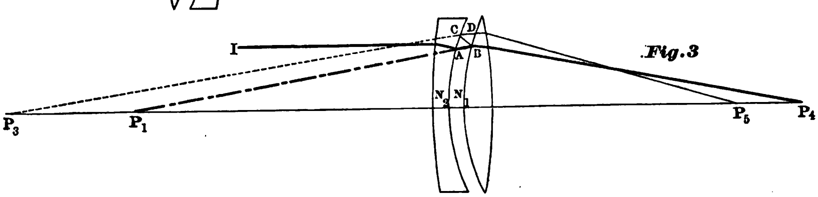


Fig.3

The ghost of the greatest practical importance, from an ordinary objective, is that projected by the two internal faces, because this is most likely to be near the focal plane. In the general form recommended by Fraunhofer and others, these faces are very nearly parallel and very near each other, the lenses being separated by bits of tin foil, and fastened in the same cell. Fig. 2 represents the crown lens toward the star, which is the usual arrangement; in Fig. 3 the position is reversed. In both figures, the distance of the lenses and the curvatures are greatly exaggerated, while the dimensions of p, p', and p'' are greatly diminished, especially in Fig. 3. I represents an incident ray, parallel to the axis.

Since one of the internal faces is convex, its radius of curvature is considered negative, and r_1+r_2 is essentially a very small negative quantity—the convex surface having a somewhat greater radius of curvature than the other. The distance d is also a very small quantity as compared with the focal distances p, and the radii of curvature taken separately r_1 and r_2. Hence, from eq. (4) we may derive—

$$P_3\, P_1 = \frac{-d\,[2\,p_1^2+(2\,p_1-r_1)\,r_2]+p_1^2\,(r_1+r_2)}{\tfrac{1}{2}\,r_1\,r_2} \quad (5)$$

as a close approximation for such object glasses. The denominator of this fraction is essentially negative, while the numerator (in any ordinary case) will be negative also. Hence, $P_3\, P_1$ is positive (as represented in Figs. 2 and 3), showing that P_3 will be further from the focal plane than P_1. This distance can not be reduced to zero, except by making (r_1+r_2) positive; that is, by making the convex face more curved than its companion; and this may interfere with the usual mode of setting, in a single cell. But we may increase the value of $P_3\, P_1$ by increasing either d or $-(r_1+r_2)$; any change in the distance of the lenses will have about twice as great an effect on the value of $P_3\, P_1$ as the same change in the difference of curvatures of the internal faces. It will scarcely be possible to find values for the curvatures which shall reduce $P_3\, P_1$ to zero, and thus make the ghost coincide with the image, while also securing the best correction for spherical and chromatic aberration. Hence the lenses should usually be placed at such a distance that the value of $P_3\, P_1$ shall be as great as consistent with the other requirements of the instrument. It may be that for special purposes (as in observations on a very faint distant companion to a star) d and $-(r_1+r_2)$ should both be made as small as possible, in order that the cone of rays which form the ghost should be intersected by the focal plane very near its apex, thus leaving the field unilluminated at a short distance from the principal image.

The positions of both the image and the ghost are indicated by the equation already given, $p''=\frac{pf}{p-f}$, where f is the focal length of the second lens, p is either p_1 or p_3, and p'' is the distance of the principal image or the ghost, as the case may be; p_1 is nearly equal to the focal length of the first lens, taken with the opposite sign.

By differentiating, $$d\,p'' = -\left(\frac{f}{p-f}\right)^2 d\,p \quad (6).$$

With glasses of usual quality, we may assume that the focal length of the crown lens is about 0.6 that of the combination*, or -0.4 that of the

* See Pickering's "*Physical Manipulations*," vol. I., p. 179.

flint lens. Hence, if the crown glass is directed toward the object (as in Fig. 2) $p_1=0.4f$, and $dp''=-\left\{\frac{1}{-0.6}\right\}^2 dp=-2.8\,dp$ nearly; that is, for very small values of $P_3\,P_1$, we may assume (for ordinary glasses)

$$\Delta p''=-2.8\,\Delta p, \text{ or } P_5\,P_4=2.8\,P_3\,P_1 \text{ nearly} \qquad (7)$$

In like manner, if the flint glass precedes (as in Fig. 3)

$$dp''=-(2/3)^2\,dp=-0.44\,dp \text{ nearly, and}$$

$$P_5\,P_4=0.44\,P_3\,P_1 \text{ nearly} \qquad (8)$$

Hence, with ordinary glasses, when the value of $P_3\,P_1$ as deduced from eq. (5) is quite small, the ghost will be between the focal plane and the lens, at a distance from the former of about 2.8 or 0.44 times $P_3\,P_1$, according as the crown or the flint glass is directed toward the star. If the ratio of the focal lengths of the lenses is different from that assumed above, other coefficients must be substituted in equations (7) and (8).

BRIGHTNESS OF THE GHOST.

The theory of light furnishes us with the equation,

$$\frac{\text{Reflected light}}{\text{Incident light}}=\left[\frac{n-1}{n+1}\right]^2$$

for rays normal to a refracting surface. If light is reflected from two glasses where $n=1.5$ and 1.6, respectively,

$$\frac{\text{Light reflected from second surface}}{\text{Light incident upon first surface}}=\left[\frac{.5}{2.5}\times\frac{.6}{2.6}\right]=0.00248.$$

Hence we may assume that the whole quantity of the light in the ghost is about ¼ of one per cent. as great as that in the image; while the brightness is inversely as the square of the distance between the image and the ghost.

If the space between the lenses is filled with a solid or liquid, the brightness of the ghost will be greatly diminished. This is accomplished in the ordinary field-glass by cementing the lenses with Canada balsam.

APPLICATION OF THE FORMULAE TO HASTINGS' 24 CM. OBJECTIVE.

The present investigation was suggested during the examination of an object glass constructed by Professor C. S. Hastings, of the Johns Hopkins University.* The following data are taken from a very interesting description by Dr. Hastings, to whom also I am indebted for valuable suggestions:

* The Jurors' Report on this Telescopic Objective is published in the "Report of the Board of Commissioners of the Cincinnati Industrial Exposition for 1881," p. 244.

Diameter, 9.4 inches.

Radii of curvature, taken in order.	Flint glass	121.2 inches,	convex.
		34.22 "	concave.
	Crown glass	34.48 "	convex.
		108.4 "	convex.

Thickness of flint glass at axis, .863 inch.
" " crown " " .808 "
Distances between the glasses " .25 " or more, adjustable.

Index of refraction for the ray whose wave length is 5614, { Flint glass, 1.617613; Crown glass, 1.524179 }

Distance of principal ghost from image, 27.4 inches. The flint lens is placed toward the object.

From these data, by the formulae of elementary optics (neglecting thickness of the glasses),

Focal length of flintlens = —77.21 inches.
" " " crownlens = 49.92 "
" " " combined lens = 141.2 "

It may seem surprising, at first sight, that the ghost can be thrown to such a distance, when the reflecting surfaces are so close and so nearly parallel. Dr. Hastings' claim, in this respect, is easily proved to be correct, by the usual formulae; and the very considerable distance of the ghost is largely due to the fact that the focal length of the crown glass is little more than one-third that of the combination. The following calculations may show how far the approximate formulae can be made available.

By eq. (4) $$P_3 P_1 = \frac{12-4620-1560}{47.35+20.14-589.9} = \frac{6168}{522.4} = 11.81$$

By eq. (5) $$P_3 P_1 = \frac{-4620-1560}{-589.9} = \frac{6180}{589.9} = 10.48$$

By eq. (6) $$dp'' = -\left(\frac{49.92}{77.46-49.92}\right)^2 dp = 3.287\, dp$$

If then we should apply equations (5) and (6), assuming that dp'' is constant during the increase of p from the value of P_1N_1 to P_3N_1, we should have for the distance of the ghost in front of image, $3.287 \times 10.48 = 34.46$. This value is too great by about one-fourth of the true value, although one error partly compensates the other. When the lenses are to be set in the same cell, these errors will be much smaller; and equation (4) or (5), combined with eq. (6), may be useful to judge of the nearness of the ghost with a proposed set of curves. The selection of a thicker piece of tin foil to separate the glasses may have a material effect upon the position of the ghost.

SCIENTIFIC PROCEEDINGS

OF THE

OHIO MECHANICS' INSTITUTE.

VOL. I. DECEMBER, 1882. NO. 4.

PROCEEDINGS OF THE DEPARTMENT OF SCIENCE AND ARTS.

Meeting of October 20.

A PAPER on "SMOKELESS COMBUSTION OF FUEL" was read by E. P. Robbins, M. E. The following is an abstract:

"The chemical changes involved in the combustion of fuel, including the distillation of the various hydrocarbons, their mutual reactions,* and their final combustion, are far more complicated than is generally supposed. A certain interval of time is required to effect these processes, which do not take place in the fire-box only, but also in the flues, as far as the flame extends. One "smoke consuming device" has even been placed in the chimney stack, in order to effect a saving of the fuel! The *place* of the combustion is a matter of importance; for the surface of the fire boxes is of no value as regards the heat generated in the flues. When air is admitted above the grate to complete the combustion, there will often be a loss of efficiency, owing to imperfect or tardy mixing with the gases to be consumed. A like waste may be caused by making the layer of fuel so thin that portions of the grate surface become bare, allowing streams of air to enter from below. The value of Watt's "dead-plate" and inclined grate bars, has not generally been appreciated; but the ash pit should be closed and the draught checked when the fuel is pushed back, to avoid an excessive supply of cold air while the grate is bare. Those who use steam seldom make adequate provision for an increased demand; and then, should the demand arise, they overtask their boilers, thus increasing smoke and wasting fuel. The best devices are

* This class of reactions is discussed by Berthelot, in "*Essai de Mécanique Chimique*," Vol. II, pp. 119–141, where references will be found to original papers. R. B. W.

unsuccessful if the boiler is overworked or if the fire is unskillfully managed."

The Chairman then announced that a course of popular lectures, to be given every Friday evening, beginning November 3, would take the place of the regular Department meetings for the winter. Called meetings may be held when necessary.

Meeting of December 1.

The following report on the "CUMMING PERIPHERY CONTACT" * was presented and read.

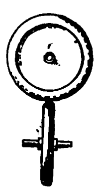
REPORT.

CINCINNATI, O., Nov. 29, 1882.

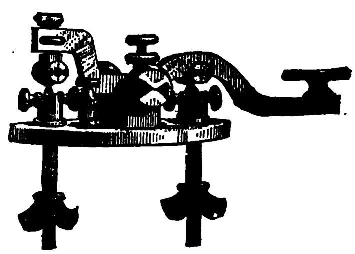
The Examining Board appointed to investigate the merits of the Cumming Periphery Contact report as follows:

In this device, as applied to the telegraph key, the electrodes consist

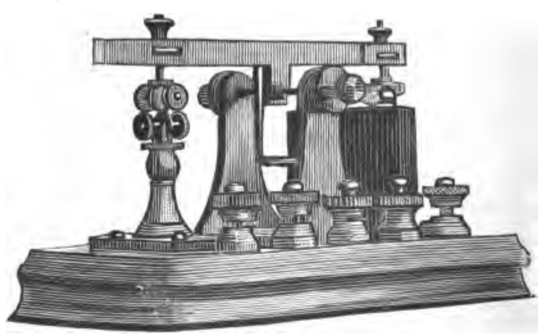
* Covered by patents No. 256,645 and No. 256,646, of April 18, 1882. See pages 8, 12, and 51, of these PROCEEDINGS. Theories of sticking, suggested by this device, will be found on pages 46–48. The following cuts illustrate this device and some of its applications. It was first used with the single current key.



DISKS FULL SIZE.



DOUBLE CURRENT KEY.



DYNAMO POLE CHANGER.

of two rollers or disks combined with the lever and the base respectively, with their planes at right angles to each other, these rollers having peripheral contact and serving as the hammer and anvil. The rim of each disk consists of a platinum wire—the surface of contact being thus reduced to a minimum, while it is impossible for the electrodes to pass each other.

We decided that a severe practical test would best serve to determine the value of the invention; the key given to us for examination was accordingly placed on duty in the Western Union Telegraph office in this city, June 17, 1882, on a press circuit working steadily from 8 A. M. to 2 A. M. every day.

The testimony of operators handling the key daily is without exception favorable to it, on account of its easy motion and freedom from sticking. It has never, to our knowledge, been taken from its bearings for the purpose of improving its efficiency, which has continued to be satisfactory to the present time. There is no mark of deterioration upon the periphery of its contact disks, except an indentation caused by a heavy weight falling upon its lever. This was remedied by turning the indented disk, so as to remove the injured part from contact.

We are led by these facts to conclude that this key is superior to the ordinary telegraph key, and that its superiority consists in the nature of the contact made by the peripheries of the revolving disks. This device may also be used with advantage in place of the ordinary contact points in other electrical instruments, where a circuit is made and broken.

We recommend the award of the Medal of the Ohio Mechanics' Institute to George Cumming of New York, in recognition of his invention as an important advance in the construction of electrical instruments.

[Signed] S. M. DUNLAP,
A. T. GOULD,
C. E. JONES,
C. B. MCMEEKIN,
EDMUND OSMOND.

This report was adopted by the Department, and the award of the medal, as recommended by the Examining Board, was confirmed.

PROCEEDINGS OF THE SECTION OF MECHANICS AND ENGINEERING.

Meeting of November 28.

A PAPER on "THE MANUFACTURE OF FIRE-ARMS" was read by Mr. Geo. W. Bugbee.

The following papers were read by title: "PUMPING ENGINES FOR PUBLIC WATER SUPPLY," and "COMPARATIVE ECONOMY TESTS OF THE GEARING BOILER FURNACE," by John W. Hill, M. E., "WEIGHT OF MEN AND WOMEN," by Mr. W. A. Collord, and "SUGGESTIONS FOR THE SCHOOL OF TECHNOLOGY," by Professor Robt. B. Warder.

PROCEEDINGS OF THE SECTION OF CHEMISTRY AND PHYSICS.

Meeting of October 26.

PAPERS were read by Professor Robt. B. Warder as follows: "A CRITERION FOR MEASUREMENTS OF THE SPEED OF CHEMICAL ACTION," "URECH'S INVESTIGATION OF THE SPEED OF INVERSION OF CANE SUGAR," "TRANSMISSION OF BRINE THROUGH GRAVEL, AND CONTAMINATION OF WATER," and "DAILY FLUCTUATION IN THE FLOW OF A CALIFORNIA STREAM."

XVII.—PUMPING ENGINES FOR PUBLIC WATER SUPPLY.

BY JOHN W. HILL, M. E.

[Read before the Section of Mechanics and Engineering, November 28, 1882.]

One of the most exalted applications of steam as a motive power is to pumping engines for a public water service. The most expensive steam engines ever built have been for this purpose, and in no other branch of the art has the same progress been made in point of economy.

During the past twenty years, many experimental pumping engines involving special improvements in the steam end, or in the pumps, have been made with a view of enhancing the economy of performance.

Notwithstanding the opinion to the contrary entertained by many eminent engineers, experience has shown that a high grade of expansion is as desirable in engines for pumping large quantities of water, as in rotative engines for marine or factory use.

This question settled—as it certainly is by the remarkable results of experiments with the Leavitt engines at Lynn and Lawrence, Mass., by the Corliss engines at Pawtucket and Providence (Pettacousett Station), R. I., by the Quintard engines at the West Side Works, Chicago, by the Allis and Reynolds engines at Milwaukee, and by the Gaskill engines at Evansville, Ind., Memphis, Tenn., and Saratoga, N. Y.,—the next step is to secure the high economy with the least first cost of engine.

All of the above pumping engines are of the compound condensing type with variable cut-off gear to the high pressure cylinders. The Lynn and Lawrence engines, the Saratoga engine, the Allis-Milwaukee engine, and the Quintard-Chicago engines, are of the non-receiver class; while the Reynolds-Milwaukee engine, the Evansville and Memphis engines, and the Pawtucket and Providence engines are of the receiver class.

It is not possible, with the limited time at command, to discuss the peculiar merits of the several pumping engines referred to; but the experience with these engines is sufficient to justify the assertion that a high grade of expansion is desirable in this class of steam machinery, providing the first cost of engine is not so great as to overbalance the gain in economy.

Of the several engines referred to, those specially entitled to consideration for future reproduction are the Quintard-Chicago engines, the Gaskill-Evansville, Memphis, and Saratoga engines, and the Reynolds-Milwaukee engine.

The Evansville and Memphis engines are substantially alike (excepting the former has piston pumps and the latter double-acting plunger pumps) and the performance of one is a reflex of the other. The Saratoga engine is the latest example of a cheap high-duty machine and the marvelous economy of this engine is the principal apology for this paper.

In the following official reports to the respective water boards of Memphis and Saratoga, are given all the material results of the contract trials, in both of which the writer had the honor of participation as an expert in behalf of the corporations.

The Memphis engine is of the vertical, rotative, receiver, compound, condensing class, whilst the Saratoga engine is of the horizontal, rotative, non-receiver, compound, condensing class.

HON. T. J. LATHAM, *President Memphis Water Co.*

DEAR SIR:—Acting in behalf of the contractor and upon the advice and with the consent of my colleague, Mr. Chas. Hermany, of Louisville, —also in your behalf, I have made duty and capacity trials of the Gaskill Compound Pumping Engines recently erected for your service by the Holly Manufacturing Company, of Lockport, N. Y.

The engines, exact duplicates, are of the compound receiver type with vertical steam and water cylinders. Each engine consists essentially of a high pressure steam cylinder, 24 inches diameter; a low pressure steam cylinder, 41 inches diameter (both steam cylinders jacketed); a fly wheel, 12·33 feet in diameter, weighing 13,000 pounds; crank shaft, with two

overhung crank arms of 18 inches radius, set at quarters and connected by heavy shackle bars with the pistons of the high and low pressure cylinders; an intermediate steam receiver; and 2 double acting plunger pumps with internally packed water joints.

The plunger of each pump is attached to the lower end of the piston rod of its corresponding steam cylinder and driven direct. The axes of the steam cylinders and crank shafts lie in a common vertical plane with the pumps at the bottom of the well, the tops of the steam cylinders nearly level with the engine room floor and the crank shafts mounted in bearings on a gallows frame overhead.

The two engines are united in a single frame work of simple and substantial design, and set up in a masonry well 18 feet diameter, and 61 feet deep from upper surface of coping stones to top of I beams upon which the pumps are set.

The pump rods are guided at frequent intervals between the steam and water cylinders by adjustable bearing blocks secured to the I beams set in the curb of the well.

The pumps are connected upon the receiving side with a 24 inch suction pipe, 210 feet long, run out through a masonry tunnel from the pump well to the Wolf River, the source of water supply, and upon the discharge side with a 24 inch rising main, which connects outside of the engine house with the principal distributing main of the direct supply system and with a small reservoir on the pumping house grounds; stop valves are provided by means of which the delivery of the pumps may be distributed direct or diverted into the reservoir.

The duty prescribed by the contract and specifications is "80,000,000 foot pounds, per 100 pounds of best coal," to be selected by the contractor, whilst pumping water for current wants and no more, and is to be estimated by the following formula:

$$D = \frac{A \times P \times F}{C} \times 100$$

in which A represents the net area of one plunger at right angles to its axis; P represents the load in pounds per square inch indicated by a correct pressure gauge attached to the rising main, at least fifty feet from the center of the pumps + vertical distance expressed in pounds pressure per square inch between center of pressure gauge and source of supply from which water is drawn + 2 pounds allowance for frictional resistance; F represents the plunger travel in feet per revolution for both pumps multiplied by the number of revolutions during the trial; and C represents the weight (in pounds) of coal burned during same interval,

with no allowance for refuse or non-combustible. The fires to be at maximum efficiency at commencement and end of trial.

The water pressure gauge was attached to rising main about sixty feet from center of pumps.

By mutual agreement of the Water Company and the contractor the engines were each to be separately tested for duty and capacity, and each engine was to be continuously operated for duty without stop or change in general conditions, except as required by variations in the public consumption of water, for a period of 18 hours, with such steam pressures as were employed in the ordinary use of the engines.

The water level in the boilers was fixed by means of strings, lashed around the glass tubes, the height of which above the glands on the water gauges was carefully measured. These levels were obtained at commencement and, at end of each trial, and were maintained practically constant during each trial.

Two boilers of the return tubular variety, each 60 inches diameter, 16 feet long, with 83 three-inch tubes, an independent steam dome and a grate surface 5 feet deep by 5·5 feet wide furnished the steam for the engines.

The boilers were supplied with feed water by an independent donkey pump taking steam from the main pipe. The feed water was drawn from the reservoir and heated with live steam; the boiler house contains four boilers, all of above dimensions, only two of which, however, were in condition for use, and the two boilers fired for the trials furnished all the steam consumed by the engines, by the donkey feed-pump, and by the feed-water heater.

During the duty trials observations of the engine counter, water and steam pressure gauges, vacuum gauge and temperature of feed water were made every 15 minutes, officially, by assistants appointed by the Water Company, and independently by observers for the contractors.

The coal fired during the duty trials was Lehigh of the best quality procurable in the Cincinnati market.

The coal usually fired is Pittsburgh; but 3 hours previous to each duty trial the grates were carefully cleaned, and firing begun with the hard coal.

Three hours previous to the completion of each trial, the grates were again cleaned of all clinker and non-combustible, in order to restore the condition of fire subsisting at commencement of trial.

The coal was weighed in the boiler house, by an assistant appointed by the Water Company, in uniform charges of 125 pounds, upon a carefully tested platform scale, and dumped, as required, in alternate charges,

before the boilers in use. After each trial began, no other coal was permitted on the boiler house floor, and all charges were consecutively numbered and time of delivery noted by the assistant in charge.

Instructions were given the fireman to maintain, as nearly as possible, a constant stated boiler pressure during each trial, and the fidelity with which this injunction was observed, is best attested by the log of boiler pressures in the records of duty trials submitted herewith.

The plungers of Engine No. 1 pumps were carefully callipered and found to measure from ·01 to ·015 inch in excess of contract diameters, from which are deduced substantially the same diameters for the plungers of Engine No. 2 pumps, for comparison of the quantities of water delivered for given revolutions during the capacity trials. (In the original projection of the pump well, it was the intention to have it dry and water tight, but, through some fault in construction, the water stands at the same level in the well as in the river. In order to drain the well, two medium size Blake steam pumps were set up in it, which, in conjunction with the injection pumps worked by the engine, were capable of lowering the water sufficiently to get at the pumps. After the duty trials were completed, the water was pumped out of the well for the purpose of disconnecting the pump heads and measuring the plungers. The plungers of Engine No. 1 were so measured, but before the pumps of Engine No. 2 could be disconnected, one of the Blake pumps gave out, and the water rose so rapidly in the well as to prevent an examination of the pumps of Engine No. 2.)

The contract diameter of plungers is 16 inches, and of rods 3·5 inches, which dimensions are adopted in the calculations for duty and capacity.

The length of all pump strokes was carefully measured from marks on the guide bars, and found to be fairly in excess of 36 inches, the contract requirements.

DUTY TRIAL OF ENGINE NO. 2.

The test for duty of Engine No. 2 commenced at 9:45 A. M., January 5, and terminated at 3:45 A. M., January 6, with the following results:

Engine counter at 9:45 A. M., January 5	76,781
" " " 3:45 " " 6	98,636
Revolutions for 18 hours	21,855

and piston travel—

$$\frac{36 \times 2 \times 21{,}855 \times 2}{12} = 262{,}260 \text{ ft.} = F.$$

Water Pressure Gauge.

Minimum reading	42·5	pounds.
Maximum "	55	"
Mean of seventy-three readings	49·996	"

One set of water and steam gauges were used for all trials, and upon completion of the records the water pressure gauge, and steam gauge, at engines, were disconnected and shipped to Cincinnati for comparison with a mercury column. They were tested upon Kirkup & Son's column and found to indicate (between pressures at which they were worked in the trials) 4·15 pounds less than the true pressure for water gauge, and 5·92 pounds less than the true pressure for steam gauge. Correcting the water pressures accordingly the

Mininum reading was	46·65	pounds.
Maximum " "	59·15	"
Mean " "	54·146	"

The vertical distance from the center of the water pressure gauge to a given bench mark in Wolf River, as measured by Mr. Meriwether, Civil Engineer, of Memphis, for the purpose of these trials is 50·47 feet and the mean relation of the level of Wolf River to this bench mark, during the trial of Engine No. 2 for duty, was + ·045 foot, and mean difference of water pressure gauge and source of supply 50·425 feet, corresponding to a pressure in pounds per square inch of

$$\frac{50{\cdot}425}{2{\cdot}31} = 21{\cdot}924,$$

and contract allowance for frictional resistance is 2 pounds; from which the total head in pounds pressure per square inch, was

$$54{\cdot}146 + 21{\cdot}924 + 2 = 78{\cdot}07 \text{ pounds} = \text{P}.$$

The area of the plunger is 201·06 square inches, and the area of the pump rod 9·62 square inches, and net area of plunger as per terms of contract is

$$\frac{(201{\cdot}06 \times 2) - 9{\cdot}62}{2} = 196{\cdot}25 \text{ sq. in.} = A.$$

The coal (C) fired, during the trial, was 33 charges of 125 pounds each, or 4,125 pounds; from which the duty of Engine No. 2, as per terms of contract, is deduced as

$$\frac{196{\cdot}25 \times 78{\cdot}07 \times 262{,}260 \times 100}{4{,}125} = 97{,}409{,}642{\cdot}35 \text{ foot pounds} = \text{D}.$$

Additional data from duty trial of Engine No. 2:

Steam pressure at boilers	82·253*
" " " engine (corrected)	81·837
Vacuum	26·717*
Temperature of feed water	142·20°

DUTY TRIAL OF ENGINE NO. 1.

The test for duty of Engine No. 1 began at 9:15 A. M., January 7, and terminated at 3:15 A. M., January 8, with the following results:

Engine counter at 9:15 A. M., January 7	56,254
" " " 3:15 " " 8	78,788
Revolutions for 18 hours	22,534

and piston travel—

$$\frac{36 \times 2 \times 22,534 \times 2}{12} = 270,408 \text{ ft.} = F.$$

Water Pressure Gauge Corrected for Error.

Minimum reading	45·15
Maximum "	57·65
Mean of seventy-three readings	51·181

The mean relation of the level of Wolf River to the bench mark, before mentioned, during the trial of Engine No. 1 for duty, was ·0113 foot, and mean vertical difference of water pressure gauge and source of supply 50·4813 feet; corresponding to a pressure in pounds per square inch of

$$\frac{50·4813}{2·3} = 21·948,$$

and contract allowance for frictional resistance, as before, 2 pounds; from which the total head in pounds pressure, per square inch, was

$$51·181 + 21·948 + 2 = 75·129 \text{ pounds} = P.$$

The area of plunger, as before, was 196·25 sq. in. $= A$.

The coal (C) fired, during the trial, was 32 charges of 125 pounds each, or 4,000 pounds; from which the duty of Engine No. 1, as per terms of contract, is deduced as

$$\frac{196·25 \times 75·129 \times 270,408 \times 100}{4,000} = 99,672,836·63 \text{ foot pounds} = \text{D}.$$

Additional data from duty trial of Engine No. 1:

Steam pressure at boilers	82·549
" " " " engine (corrected)	81·825
Vacuum	27·620
Temperature of feed water	160·180

* No tests were made of these gauges, and their errors are unknown. The boiler gauge probably indicates less than the true pressure.

Just before the completion of the duty trial of each engine, all the principal bearings were carefully examined and found in excellent condition, with no evidences of warming. The contract provides that each engine shall be capable of pumping 4,000,000 gallons in 24 hours, at a piston speed of 155 feet, and that this work shall be done easily, without overstrain of any part of the machine.

The specifications provide that this quantity of water shall be delivered against a head as indicated upon the water pressure gauge of 65 pounds, and that the discharge shall be measured over a weir.

The original specifications provide that the vertical distance from the engine room floor to low water mark shall be 42 feet, and vertical distance from same datum to center of water pressure gauge shall be 6 feet, or total difference of low water mark and water pressure gauge 48 feet.

In the construction of the pump house the engine room floor was elevated 72·36 feet above low water mark, and the water pressure gauge was located 8·28 feet above engine room floor, making total distance from center of water pressure gauge to low water mark 80·64 feet, or 32·64 feet higher than provided in the original specifications. The difference in elevation equivalent to a pressure of 14·2 pound per square inch must be deducted from the pressure by gauge against which the engines are required to pump by the specifications, in order that the actual head pumped against for capacity test shall equal the head provided by the terms of the contract.

The minimum gauge pressure for capacity tests was accordingly fixed at 51 pounds, which pressure was obtained by partially closing a stop valve in the discharge pipe.

The engines pump into the mains upon the direct supply system, and the cutting of the principal distribution for the purpose of weir measurements involved a stoppage of the machinery, and a corresponding loss of water to the consumers. Upon consultation with the Water Company and the contractor, it was decided to abandon the weir measurements and test the capacity of the engine by pumping into the small reservoir at the pumping station. In furtherance of this plan the distribution main was cut and a new stop valve beyond the branch inserted, leading to the reservoir, in order that all leakage should be confined to the reservoir proper and its immediate connections.

The reservoir was carefully measured for the purpose of the capacity trials by Mr. Meriwether, and found to have the following dimensions at the surface of the banks:

Length, mean of both sides	255·6 feet.
Width, mean of both ends	130·925 "
Depth	15·775 "
Angle of inside slope	35° 45′

The corners of the reservoir are 90° arcs of circles, to which the sides and ends are tangent with a radius of 19 feet at the surface of the banks, and O at the bottom of the slope, where the horizontal section is a true rectangle.

To determine the leakage of the reservoir, all connections therewith were closed, and the level carefully taken at 3:00 P. M., January 8, and again at 5:00 P. M., 2 hours later.

3:00 P. M., head on reservoir gauge	12·73 feet.
5:00 " " " " "	12·7092 "
Reduction of head in 2 hours	·0208 feet.

From this data and the reservoir measurements above given, the leakage is estimated as 631·349 cubic feet for two hours, or at the rate of 2361·25 gallons per hour at observed head.

The duration of the capacity trials was fixed at 5 hours for each engine, during which time all water pumped was delivered into the reservoir.

The capacity trial of Engine No. 1 began at 12:17 A. M., January 10, and terminated at 5:17 A. M., same date, with the following results:

Engine counter at 12:17 A. M.	93,624
" " " 5:17 "	101,358
Revolutions in 5 hours	7,734

and piston speed—

$$\frac{7,734}{50} = 154{\cdot}68 \text{ feet per minute.}$$

Water Pressure Gauge.

Minimum reading (corrected)	56·15 pounds.
Maximum " "	61·65 "
Mean of eleven readings	58·55 "
Head in reservoir at 12:17 A. M	8·5 feet.
" " " " 5:17 "	12·917 "
Head added in 5 hours	4·417 feet.

The surface area of the reservoir at head of 8·5 feet, computed from Mr. Meriwether's data, is 25,967·735 square feet, at head of 12·917 feet is 30,249·893 square feet, and midway between these heads is 27,961·022 square feet.

Then, by prismoidal formula, the water added to reservoir was

$$\frac{(27{,}961{\cdot}022 \times 4) + 25{,}967{\cdot}735 + 30{,}249{\cdot}893 \times 4{\cdot}417 \times 7{\cdot}48}{6} = 925{,}436{\cdot}32 \text{ gallons;}$$

to which must be added the leakage of reservoir for a period of 5 hours, or

$$\frac{2{,}361{\cdot}25 \times \sqrt{10{\cdot}708} \times 5}{\sqrt{12{\cdot}72}} = 10{,}832{\cdot}35 \text{ gallons;}$$

making total delivery into reservoir during capacity trial of Engine No. 1 of 936,268·67 gallons. Of this quantity a portion was the excess of injection water pumped into the reservoir.

The condensers furnished with the engines receive their injection water from the reservoir, the supply for which is raised from the pump well, or main suction pipe, by a double-acting piston pump (one to each engine), worked by a lever from one of the main pump rods.

The injection pumps are required to raise the water from the level in Wolf River to the reservoir against a head (during the capacity trials) of 50 feet, from which source the injection is drawn by gravity.

The capacity of the injection pumps is considerably in excess of the requirements of the condensers, and a certain surplus of water was in this manner delivered in the reservoir during the capacity trials, which has been estimated as follows:

Each injection pump has a diameter of 9 inches, and a stroke of 12·75 inches, with a rod (probably) 1·5 inch diameter, and, allowing a moderate loss of action, delivered 6·58 gallons per revolution, or 50,889·72 gallons during capacity trials of Engine No. 1. Of this quantity, from estimate based upon the known economy of engine, 37,847·08 gallons were absorbed by the condenser, leaving 13,042·64 gallons in the reservoir, from which is deduced the net delivery of main pumps for a period of 5 hours as 923,226·03 gallons, corresponding to a daily delivery under the terms of contract of 4,431,484·94 gallons.

The calculated delivery of 2 pumps per revolution is 122·34 gallons, and for 5 hours 122·34 × 7,734 = 946,177·56 gallons; from which the loss of action is deduced, as

$$100 - \frac{923{,}226{\cdot}03}{946{,}177{\cdot}56} \times 100 = 2{\cdot}43 \text{ per cent.}$$

The pumps received water under a head of 12 feet.

The capacity trial of Engine No. 2 commenced at 12:05 A.M., January 11, and terminated at 5:05 A. M., same date, with the following results:

Engine counter at 12:05 A. M.	149,971
" " " 5:05 "	157,722
Revolutions in 5 hours	7,751

and piston speed—

$$\frac{7,751}{50} = 155 \cdot 02 \text{ feet per minute.}$$

Water Pressure Gauge.

Minimum reading (corrected)	56·15 pounds.
Maximum " "	59·15 "
Mean of eleven readings	57·075 "
Head in reservoir at 12:05 A. M.	8·2708 feet.
" " " " 5:05 "	12·7083 "
Head added in 5 hours	4·4375 feet.

The surface area of reservoir at head of 8·2708 feet computed from the data above given is 25,742.537 square feet, at head of 12·7083 feet is 30,043.361 square feet, and midway between these heads is 27,865.848 square feet. Then, by prismoidal formula, the water added to reservoir was

$$\frac{(27,865.848 \times 5) + 25,742.537 + 30,043.361 \times 4 \cdot 4375 \times 7 \cdot 48}{6} = 927,480 \cdot 95 \text{ gallons;}$$

to which is added the leakage of reservoir for a period of 5 hours, or

$$\frac{2,361 \cdot 25 \times \sqrt{10 \cdot 49} \times 5}{\sqrt{12 \cdot 72}} = 10,721 \cdot 5 \text{ gallons;}$$

making a total delivery into reservoir during capacity trial of Engine No. 2 of 938,202·45 gallons.

Of this quantity a portion was the surplus of injection, as before. Estimating net delivery of injection pump per revolution at 6·58 gallons, or 51,001.58 gallons during capacity test of Engine No. 2, and computing from economy of engine, as before—37,930·29 gallons absorbed by the condenser—then surplus of injection water pumped into reservoir was 13,071·29 gallons, and net delivery of main pumps for a period of 5 hours was 925,131·16 gallons; corresponding to a daily delivery under terms of contract of 4,440,629·57 gallons.

The calculated discharge for the 5 hours capacity trial of Engine No. 2 is $122 \cdot 34 \times 7,751 = 948,257 \cdot 34$ gallons; from which the loss of action is deduced as

$$100 - \frac{925,131 \cdot 16}{948,257 \cdot 34} \times 100 = 2 \cdot 44 \text{ per cent.}$$

The close approximation of the slip in the trials for capacity, based upon independent measurements of water delivered, justifies the belief previously expressed, that the plungers of Engine No. 2 were sensibly of the same diameters as the plungers of Engine No. 1, which latter were carefully measured after the duty trials.

The engines were started about 3 months previous to the trials, and have been in constant operation—working together usually—ever since.

In fact, these engines are at present the sole reliance of the service, and the very creditable manner in which they are performing, sanctions the opinion that the faith of the Water Company has not been misplaced.

It will be observed in both duty and capacity performance that the engines have exceeded the contractor's guarantees in an extraordinary manner.

All of which is respectfully submitted. JOHN W. HILL.

CINCINNATI, *January* 20, 1882.

To the Honorable Board of Water Commissioners, Saratoga Springs, N. Y.:

GENTLEMEN:—Acting respectively for and in behalf of your Board, and of the contractor, we have made a careful examination of the Gaskill Compound Pumping Engine recently erected for your public water service by the Holly Manufacturing Company of Lockport, N. Y., and beg to report thereon as follows:

The engine is horizontal, of the rotative, non-receiver, compound-beam type, and involves a novel arrangement of the several members, whereby a large capacity and a high economy are obtained by a simple machine in a small compass. The contract provides that the engine shall "have four steam cylinders arranged in pairs; one high pressure cylinder and one low pressure cylinder in each pair, the low pressure cylinder placed under the high pressure cylinder. There will be one pump to each pair of steam cylinders. The whole bolted to a heavy cast iron bed-plate, which is bolted (in turn) to stone foundations. The fly-wheel will revolve between the two pump cylinders. The crank shaft to have its pillow blocks one on each pump cylinder. The cross heads of the high pressure cylinders will be connected by suitable links to a beam which will be in turn connected one end to the crank and the other end to the piston rod of the low pressure cylinders and pumps. The supports for the beam will rest on and be firmly bolted to the base."

"The steam cylinders will be four in number; two high pressure cylinders, 21 inches diameter and 36 inch stroke of pistons, and two low pressure cylinders, 42 inches diameter and 36 inch stroke of piston; to be steam jacketed on sides and heads."

"The pumps will be two in number, and will be of the kind known as double-acting, plunger pumps, the plungers of which will be 20 inches diameter and 36 inch stroke, and will be packed with an internal gland, which will be adjusted by means of bolts passing through the rear of the pumps, and will be made easy of access by means of hand holes placed in the pump cylinders. The pump piston rods will be two in number one for each pump, and will be 4 inches diameter."

The contract provides that the engine shall have a "pumping capacity of four million U. S. gallons in twenty-four hours," against a domestic pressure of "eighty pounds per square inch at eighteen revolutions per minute," and shall develop a duty the equivalent of "eighty million pounds of water raised one foot high" with a consumption of "one hundred pounds of the best coal."

The contract further provides that the engine shall "with safety to all its parts," carry a fire pressure of one hundred and forty pounds per square inch and shall be capable "of working safely at thirty revolutions per minute," and shall have an "average daily duty of sixty-five million foot pounds with good merchantable anthracite coal, said average daily duty" to be determined by the engineer at the works, who shall keep a daily record of the coal consumed and the work performed by the engines and pumps.

Omitting the daily average duty of "sixty-five millions" which by the terms of the contract is not within the purview of our investigation, we have endeavored to ascertain the compliance of the engine and boilers (the contractor having furnished the entire plant) with the following requirements of the contract.

First, *A delivery into the mains at eighty pounds pressure, of four million standard gallons of water, the engine working at a speed not in excess of eighteen revolutions per minute.*

The plunger diameter and strokes were carefully measured and found to be exactly in accordance with the specified dimensions, or 20 inches diameter, and 36 inch stroke with rods 4 inches diameter.

The calculated delivery of two such plungers per double stroke or per revolution of engine is 191·923 gallons, of which quantity we estimate, from previous experiments upon pumps in all material respects like these, 97·5 per cent. will be actually delivered to the force pipe, or 187·125 gallons per revolution, and at 18 revolutions per minute for 24 hours, an actual delivery of $187·125 \times 18 \times 60 \times 24 = 4,850,280$ gallons, or an excess of 21·257 per cent. over contractor's guarantee.

During the duty trial of November 1st and 2d, the engine ran at an average speed of 17,874·2 revolutions per minute, corresponding to actual daily delivery with an estimated slip or loss of action 2·5 per cent. of 4,816,371·02 gallons, against an average observed pressure upon contractor's gauge and special test gauge of 95·07 pounds per square inch. It is scarcely necessary to suggest that if the engine is capable of pumping the above quantity of water against a pressure of 95 pounds per square

inch, that it is capable of pumping a larger quantity against a reduced pressure, say 80 pounds, with the same boiler pressure.

The pumps by reason of the very low speed at which they are now worked are supplied with ordinary bye pass pipes and valves to adapt the water load to the reduced motion of engine.

During the trial of November 1st and 2d, the bye passes were closed and pumps required to furnish a full delivery of water.

Second, *A duty of eighty million pounds of water raised one foot high, with a consumption of one hundred pounds of best coal.*

The duty trial began at 8 A. M., November 1st, and terminated at 4 A. M., November 2d, covering an unbroken run of twenty hours, during which time at regular intervals observations were made of the engine counter; steam and water pressure gauges; water levels in boilers; temperatures of injection, overflow, water to heater, and feed water to boilers; meter in feed pipe; and vacuum gauge.

The coal burned was "Lackawanna" of excellent quality, as shown by the remarkably small percentage of refuse during the trial. This was weighed in double charges of 150 pounds each and dumped into the coal wagon in front of the boilers; each charge to the boilers of 300 pounds was exhausted before the next charge was permitted in the wagon.

Indicator diagrams from all the steam cylinders were taken at irregular intervals during the trial.

From the log of trial are obtained the following averages and totals as affecting the duty:

DATA FROM DUTY TRIAL.

Engine Counter at 8:00 a. m., November 1st	286,053	
" " " 4:00 a. m., " 2d	307,502	
Revolutions for 20 hours	21,449	
Average pressure by water gauge	95·06875	pounds.
" " by engine steam gauge	74·25	"
" " by vacuum gauge	27·295	"
" temperature of injection	56·2250	"
" " of overflow	71·1250	"
Total coal burned	6,750	"

From which data we deduce the duty as follows:

First, by the generally adopted method of

$$D = \frac{A \times P \times F \times 100}{C},$$

where A represents the mean area of one plunger at right angles to its axis; P represents the total pressure per square inch of plunger, and

consists, first, of the observed pressure by gauge + or — difference of levels (center of water pressure gauge and source of supply) + an allowance for extra frictional resistances of water passages into and out of pumps—usually taken at one pound; F represents the total plunger travel during trial, in feet; C represents the total coal burned during trial; the condition of fires being alike at beginning and end of trial, with minimum fluctuations of steam pressure and water levels in boilers.

Second, as a net or absolute duty by the method

$$D = \frac{G \times W \times H \times 100}{C},$$

where G represents the actual delivery of water during trial in U. S. standard gallons; W the weight of water at observed temperature per gallon; H the head in feet through which the water is pumped, consisting of the algebraic sum of the head due pressure by gauge, and the difference of levels, (center of water pressure guage and source of supply); C as before represents the total coal burned during trial.

Calculating duty by first method, $A = 307{\cdot}8768$ square inches.

Pressure by gauge, mean of 81 readings	95·06875
Difference levels center of water pressure gauge and source of supply	·09965
Allowance for extra frictional resistance of water passages into and out of pumps	1·0000
P = sum =	96·1684 lbs.
Revolutions during trials	21,449
Piston travel per revolution	12
F = product =	257,388 feet.
C = total coal burned	6,750 lbs.

Then by formula,

$$\frac{307{\cdot}8768 \times 96{\cdot}1684 \times 257{,}388{\cdot} \times 100}{6{,}750} = 112{,}899{,}983{\cdot}104$$

foot pounds duty, or the work of raising nearly one hundred and thirteen million pounds of water one foot high, without frictional resistance or loss of effect.

The contract provides for a duty of eighty millions, which is exceeded by the duty based upon the conventional formula by 41·125 *per cent.*

Calculating the duty by second method:

$G = 191{\cdot}923 \times {\cdot}975 \times 21{,}449 = 4{,}013{,}642{\cdot}516$. galls.

W = weight per gallon taken for temp. 56°..8·33 lbs.

Pressure by gauge 95·06875×2·308	219·418
Difference levels center of gauge and source of supply	0·230
H = sum =	219·648 feet.
C = total coal burned	6,750 lbs.

Then by formula,

$$\frac{4{,}013{,}642\cdot516 \times 8\cdot33 \times 219\cdot648 \times 100}{6{,}750} = 108{,}793{,}535\cdot3$$

pounds of water raised one foot high as the equivalent of absolute duty.

The contract provides for a duty of eighty millions, which is exceeded by the net duty nearly 36 per cent.

In the following table are recapitulated the averages of all data and totals for duty trial.

Duration of trial, hours	20
Average pressure by engine gauge, pounds	74·25
Average vacuum formed, inches	27·295
Average temperature of injection (Fahr.)	56·225
Average temperature of overflow (Fahr.)	71·125
Average temperature of feed water to boilers (Fahr.)	169·175
Average pressures by gauge on force main, pounds	95·06875
Difference levels center of pressure gauge and source of supply, pounds	·09965
Revolutions in 20 hours	21449
Revolutions per minute	17·8742
Piston speed per minute, feet	107·2452
Total coal burned, pounds	6,750
Calculated discharge of pumps per revolution, gallons	191·923
Actual estimated discharge of pumps per revolution, gallons	187·125
Weight of water per gallon at 56° Fahr., pounds	8·33
Contract delivery at 18 revolutions, gallons	4,000,000
Actual (estimated) delivery at 18 revolutions, gallons	4,850,280
Excess over contractor's guarantee, per cent	21·257
Contract duty per 100 pounds coal	80,000,000
Conventional duty as per trial	112,899,983·104
Excess over contractor's guarantee, per cent	41·125
Net absolute duty as per trial	108,793,535·3
Excess over contractor's guarantee, per cent	36

Just before the duty trial terminated all the principal bearings of the engine were examined with no evidences of heating.

Third, *The furnishing of a fire pressure of one hundred and forty pounds per square inch with safety to all parts of the engine.*

This is a moderate requirement, as pumping engines for fire service are usually constructed to withstand one hundred and fifty pounds pressure per square inch of plunger or piston, and are not unfrequently required to furnish a fire pressure of 180 to 200 pounds per square inch in towns built on undulating ground. Without special observation there is little

doubt of the ability of the engine to meet this requirement with a large factor of safety, but during the test of fire streams, Saturday, October 28, the gauge was read at frequent intervals and occasionally registered in excess of 140 pounds.

Fourth, *The engine shall be capable of working safely at thirty revolutions per minute.*

It is not possible to properly test the engine at thirty revolutions per minute with the present connecting mains. But from the manner in which the engine performed during the duty trial and our previous experience with similar pumping engines, there is no reasonable doubt of the dimensions and arrangement of parts being sufficient and well adapted for such a speed as a maximum requirement.

As a matter of interest to your board, and ourselves, arrangements were made to determine the economy of the boilers during the duty trial, with the following results:

Duration of trial, hours	20
Average pressure by gauge, pounds	76·644
Average temperature of feed water	169·175
Average temperature of water to meter	85·575
Average percentage of water entrained	6·273
Water by meter record, cubic feet	1181·8
Error of meter record, percentage	2·8457
Weight of water per cubic foot (tem. 85·575°), pounds	62·135
Weight of water passed through meter, pounds	75,520·773
Weight of water drawn off for temperature of feed, pounds,	214
Weight of water to boilers, pounds	75,306·773
Weight of water entrained, pounds	4,723·994
Weight of net steam, pounds	70,582·779
Weight of coal burned, pounds	6,750
Steam per pound of coal from temperature of feed, pounds,	10·4567
Steam per pound of coal from and at 212°, pounds	11·286
Weight of ash and clinker returned	216
Percentage of non-combustible	3·2
Coal burned per square foot of grate surface per hour, pounds	5·833
Steam per square foot of heating surface per hour, pounds	1·1933

The specifications for the engine provides for air pumps to remove the air, water of condensation, and condensing water from jet condensers, to be worked from the engine shaft. In place of these the contractor has substituted the now well-known Bulkley condensing apparatus. The merit of this change must be measured by the results. The vacuum obtained ranges from 27 to 28 inches, and the engine power which with air pumps would be absorbed in discharging the contents of

the condensers is now utilized in forcing water into the mains. Whatever gain in economy of performance has been obtained by the change in condensing apparatus is a benefit to the contractor in his increased duty upon trial and a continuous benefit to the water service to the extent of power which otherwise would be required to work the air pumps.

The specifications provide for an automatic pressure regulator to be furnished with the engine. This, as the contractor informs us, will be supplied and attached in due time.

Barring an unevenness of some bearings (which a limited use and proper attention to working joints will soon remedy) the performance of the engine is very satisfactory.

There is a defect in the cut off valve motion of the left engine to which we have called the contractor's attention and which he promises to correct. When corrected, the present hesitation of the engine in turning the right inboard center will disappear.

In conclusion we beg to suggest as our opinion that the engine complies in all essential respects with the terms of the contract and should be accepted.

All of which is respectfully submitted,

JOHN W. HILL,
D. M. GREENE.

Troy, New York, November 3, 1882.

PRINCIPAL DIMENSIONS OF ENGINE.

H. P. cylinder (2) diameter	21	inches.
L. P. " (2) "	42	"
H. P. piston rods (2) diameter	3	"
L. P. " " (4) "	3·5	"
Pump Plungers (2) "	20	"
" " rods (2) "	4	"
Stroke of all pistons and plungers	36	"
Cut off valves		Poppet.
Intermediate valves		Gridiron slide.
L. P. cylinder exhaust valves		" "
Fly wheel diameter	12·33	feet.
" " weight	12·000	pounds.

PRINCIPAL DIMENSIONS OF BOILERS.

Number		Two.
Style		Horizontal return tubular.
Diameter of shells	5·5	feet.
Length	18·	"
Number of tubes	87·	
Diameter of tubes outside	3·	inches.

Grates (2) length	4·75	feet.
Grates (2) width	6·	"
Heating surface estimated	2957·5	sq. feet.
Grate surface	57·	sq. feet.
Heating to grate surface, ratio	51·89	

XVIII.—COMPARATIVE ECONOMY TESTS OF THE GEARING BOILER FURNACE.

By John W. Hill, M. E.

[Read before the Section of Mechanics and Engineering, November 28, 1882.]

In the Gearing setting, the ordinary grate bed is arranged about three feet beneath the boiler shell, and fire-doors are hinged in the exterior walls of shallow chambers, or forward extensions of the furnace front. In the upper inner angle of these extensions two pipes are arranged, one directly over the other, passing horizontally before the cast iron furnace front, and through the series of extensions—there being three of these extensions (and, consequently, three fire-doors) to the battery of two boilers.

Those portions of the horizontal pipes within the extensions have a limited number of perforations (three to five) opening inward toward the fuel bed; and the pipes are arranged for rotation to determine the relative inclination of the axes of the perforations toward the fuel bed, at the will of the attendant. The pipes connect with hot air flues, built in the brick setting of the furnace, and each air blast is driven by a minute jet of superheated steam entering the pipes, respectively, at the side of the battery.

The fire doors are constructed with air openings, controlled by dampers, and an inner deflecting shield to heat the air and direct it downward to the grate surface.

Comparative trials of a battery of boilers set with the Gearing system of hot blast furnace, and of a battery of boilers set in the ordinary manner, were made on the 8th of November, at the rolling mills of the Swift Iron and Steel Company, Newport, Ky.

Each battery of boilers contained two double-flue boilers of the following dimensions:

Shell, length	28	feet.
" diameter	44	inches.
Flues, two, diameter, outside	16	"
Grate, length	3·5	feet.
" width, continuous	10	"

Chimney, diameter	45·5	inches.
" height from grate, Gearing	60	feet.
" " " " ordinary	59	"
Heating surface of two shells	387·044	
" " " four flues	469·146	
" " " four heads	15·533	
Total	871·723	sq. ft.
Grate surface	35	"
Cross section of flues	5·585	"
Ratio of heating to grate surface	24·906	
" " grate surface to cross section of flues	6·267	
" " " " " " " " chimney	3·1	

The two batteries of boilers were set side by side, were exactly alike in all respects save in the setting, and were worked under the same conditions for the same time.

The feed water to both batteries of boilers was under the control of the mill engineer, and the fuel was weighed up and burned from the pile found in front of the boilers.

The coal was fired, partly by Mr. Gearing and partly by the fireman. Both furnaces were cleaned of ash and clinker just previous to the trials, and were in all known respects in good condition.

The steam pressure, temperatures of feed water, and coal burned, were such as are usually employed, and the results of the trials are calculated to exhibit the average daily performance of the furnaces or settings.

In the following table I have given all the principal data from the trials, which lasted ten hours.

General Observations.

	Gearing.	Ordinary.
Average steam pressure, lbs. per sq. in	75·875	83·675
" temperature of atmosphere (Fahr.)	68·275°	58·600°
" " " feed-water	168·550°	168·816°
" " " waste gases	632·925°	633·600°
Water to Boilers.		
Water pumped into boilers, cu. ft.	352·50	470·94
" " " " lbs	21431	28629
Calorimeter.		
Weight of water heated, lbs	1200	1200
" " steam condensed, lbs	62·875	60·375
Average initial temperature	80·167°	86·583°
" final "	135·500°	136·833°
" initial heat units per lb. of water	80·193	86·620
" final " " " "	135·705	137·045
" increase in heat units per lb. of water heated,	55·512	50·425

Average heat units per lb. of steam condensed	1195·211	1195·293
Heat units per lb. of saturated steam	1211·67	1213·47
Latent heat units per lb. of saturated steam	888·1	883·6
Efficiency of the steam, per cent	98·641	93·887
Water entrained in the steam, per cent	1·853	8·395
Net saturated steam furnished, lbs	21033·728	26225·699

Coal.

Total coal charged, lbs	3000	4800
Coal weighed back at end of trial	318	266
Net coal actually fired	2682	4534
Ash, clinker, and unburnt coal from ash pits, at end of trial	264	199
Ratio of combustible to coal	·9016	·9561
Percentage of refuse	9·84	4·39

Economy.

Apparent evaporation from temperature of feed water per lb. of coal, lbs	7·9906	6·3143
Actual evaporation from temperature of feed water per lb. of coal, lbs	7·8425	5·7839
Heat units in feed water, per lb	168·9807	169·2489
Evaporation from and at 212° Fahr., per lb. of coal, lbs	8·4652	6·2523
Evaporation from and at 212° Fahr., per lb. of combustible, lbs	9·3891	6.5394
Relative efficiency based on coal	135·38	100·00
" " " " combustible	143·58	100·00
Gain by Gearing over common setting, per cent.	43·58	

Capacity.

Coal burned per sq. ft. of grate, per hour	15·326	25·909
Steam furnished per sq. ft. of heating surface, per hour	4·826	6·017

The efficiency based upon combustible is to be preferred in all cases, as it eliminates the coal charged on the grate and lost in the ash pit, and involves only so much of the fuel as is actually burned to gas. Upon this basis the Gearing furnace, or setting, shows a gain over the common method of setting boilers of 43·58 per cent.

In estimating the economy I have made no deduction for the small quantity of steam expended as maintaining the jets of the Gearing furnace. This amounts to about ·2 lb. per hour, and has no significant bearing upon the results.

A fair evaporation for flue boilers with common setting, burning bituminous slack of good quality, is about six pounds—rarely more than this, and often less—and the evaporation in this instance, of the boilers with common setting, is fully up to the average.

During the trials, the chimney of the boilers set with the ordinary furnace emitted the usual quantity of smoke, from ordinary to dense black; the chimney of the boiler set with the Gearing furnace showed a slight smoke while flue doors were open for charging coal, and a very faint smoke when breaking fires, with none at all after fire doors were closed.

If the Gearing furnace had been fired by a younger and more active man, I believe that better results would have been obtained from the setting.

The setting is entirely practical and inexpensive, and requires no special skill in working the fires; and more nearly complies with my standard for a smoke-preventing boiler furnace than any other which I have tested.

CINCINNATI, *November* 11, 1882.

XIX.—AVERAGE WEIGHTS OF MEN AND WOMEN.

BY W. A. COLLORD.

[Read before the Section of Mechanics and Engineering, November 28, 1882.]

AT the Tenth Cincinnati Industrial Exposition, October, 1882, permission was given to the Department of Scientific and Educational Appliances to employ a clerk to record the weights of men and women weighed on scales in the exhibit of the Howe Scale Company.

The object sought was a determination of the average weights of men and women, a fact often required by civil and mechanical engineers. Haswell states that the average weights of 20,000 men and women, weighed at Boston in 1864, were—men 141·5 lbs.; women, 124·5 lbs. These weights have been thought too low for Western people. The values obtained at the Tenth Cincinnati Industrial Exposition were as follows:

Men weighed	7,467,	weight 1,150,108 lbs.,	average,	154·02 lbs.
Women weighed	14,688,	" 1,922,198 "	"	130·87 "
Total	22,155,	" 3,072,306 "		

For men, this is 12·52 lbs. higher than the Boston average; and for women, 6·37 lbs. higher.

The average weights of people from the country, independently of the

general average, were also determined with reasonable certainty. This was rendered possible by the excursions that were coming here at various times from this and adjoining States, parts of which were weighed.

For Ohio	141 men; average weight,	157·38 lbs.
For Southern Indiana and Illinois,	124 men; average weight,	158·52 "
For Kentucky	114 men; average weight,	158·43 "
	Mean,	158·11 "
For Ohio	179 women; average weight,	133·26 "
For Southern Ind. and Illinois,	193 women; average weight,	133·55 "
For Kentucky	188 women; average weight,	133·76 "
	Mean,	133·52 "

The mean of these averages is so much above the general average as to attract attention. For men it is 4·09 lbs. higher, and for women 2·65 lbs. The very high and approximately equal averages of those from Southern Indiana and Illinois, and from Kentucky recall the Kentucky origin of the former.

XX.—A CRITERION FOR MEASUREMENTS OF THE SPEED OF CHEMICAL ACTION.

By Robt. B. Warder.

[Read before the Section of Chemistry and Physics, October 26, 1882.]

Many recent investigations relate to the speed of chemical action; * the mathematical theory has been well developed; and the hypothesis seems to be generally confirmed, that *under like conditions of temperature etc., the speed must be proportional to the product of the masses of the bodies that take part in the reaction.* † Many experimenters, however, publish their results in such form that the reader does not know whether they accord with this theory of the "action of mass" or not. Careful attention to the mathematical interpretation of such investigations would yield a rich reward: first, in affording valuable criteria of the experimental accuracy of the observations; second, in further developments of the theory of the action of mass; and third, in rendering possible a more complete numerical comparison of the coefficients of speed for various reactions.

*See an historical review by Muir, in Philos. Mag. [5] **8**, 181; and other references from papers in Ber. d. chem. Gesel. **10**, 669; **13**, 531, and Amer. Chem. Jour. **3**, 340.

† Berthollet said, as early as 1803, in *Statique Chimique*, Vol. I, p. 2, "Toute substance qui tend à entrer en combinaison, agit *en raison* de son affinité et *de sa quantité*."

A general rule will here be stated, for the application of a criterion to a series of observations; illustrations will be found in the next paper.

RULE.—*Transform the equation, if needful, so that some constant is expressed in terms of the record of experiments. Deduce the value of this constant from each equation of observation, and subtract the mean from the values so found. If the plus and minus differences tend to increase or decrease with any regularity, some disturbing cause must be eliminated before the work is complete.*

When these differences are quite irregularly distributed, they may generally be ascribed to errors affecting the several experiments, rather than the whole series. It is then well to find the mean value and the probable error, to show how closely the series agrees with theory.

The writer has already used this criterion in his experiments on the speed of saponification of ethyl acetate, to detect and eliminate various sources of error. See American Chemical Journal, **3**, 340.

XXI.—URECH'S INVESTIGATION OF THE SPEED OF INVERSION OF CANE SUGAR.

BY ROBT. B. WARDER.

[Read before the Section of Chemistry and Physics, October 26, 1882. Dr. Urech is responsible for those statements only which are expressly credited to him.]

DR. F. URECH, of Stuttgart, published a preliminary notice* on the inversion of cane sugar, about two years ago. This paper showed that the inversion by means of chlorhydric acid could be completed at 23° C. in six or seven hours. Observations were taken with Wild's polaristrobometer at intervals of five minutes. The reaction was shown to be most rapid at the beginning, more than one-half of the sugar being converted into dextrose and levulose during the first hour; and the gradual diminution of speed is in general accordance with the usual observations upon the "action of mass." The irregularity in the numerical results is easily accounted for by the numerous experimental difficulties that affect this class of work.

Now to apply the criterion, stated in the last paper, to Dr. Urech's published table of observations, we must remember that sucrose is the only active body whose mass is essentially altered during the experiment; the water consumed in the reaction,

$$C_6H_{11}O_5.O.C_6H_{11}O_5+H.O.H=C_6H_{12}O_6+C_6H_{12}O_6,$$

* Ber. d. chem. Gesel. **13**, 1696. Additional experiments are described in Ber. **15**, 2130, 2457, and in a private communication to the writer.

being very small in proportion to the whole quantity of water present. The speed of the reaction should then be proportional to the quantity of sucrose present, or

$$\frac{-du}{dt} = au \ (1),$$

where the differential coefficient represents the rate of decrease in the quantity of sucrose, u, and a is some constant.

$$\text{From eq. (1), } \frac{-du}{u} = a\,dt.$$

$$\text{By integration, } -\log_e u = at + C$$

$$\text{or } -\log_e u = at - \log_e u_0 \quad (2),$$

where $\log_e$ represents the Naperian logarithm, and u_0 is the initial quantity of the active body.

$$\text{By transposing and reducing, } a = \frac{\log_e \frac{u}{u_0}}{t} \quad (3).$$

If u_0 is assumed equal to unity, $C = \log_e u_0 = 0$, and $-\log_e u = at$, or

$$a = \frac{-\log_e u}{t} \quad (4).$$

Now since the labor of applying the formulæ is doubtless a real hindrance to their more general use, it is intended, in this paper, to illustrate the shortest possible method, both of applying the criterion, and of deducing the coefficient of speed. Thus, to avoid the frequent use of Naperian logarithms, we may assume $A = 0.4343\,a = \frac{-\log u}{t}$, and find the values of A, or any other multiple, instead of a.

Dr. Urech traces the progress of inversion by the action of the solution upon polarized light. The final reading differs from the first by 18° 42′= 1122′. The difference between any reading of the polariscope and its final reading, expressed in minutes, will therefore represent 1122 times the quantity of sucrose that still remains to be inverted, if the initial quantity is taken as unity.

It is a great saving of labor to make the calculations in parallel columns, as in the table subjoined.* The time from the beginning of the reaction is expressed in minutes, under t. The difference between the corresponding reading, and the final reading of the polaristrobometer, expressed in seconds, is recorded in the next column, and the expression "1122 u" is written at the top, as already explained. The logarithms

*This plan is strongly recommended for various kinds of physical work in Pickering's "*Physical Manipulations*," Vol. I., page 9.

must next be found. Simple inspection shows that the errors of observation amount to at least five or ten minutes, in numbers under 1,000. Three-place logarithms* will therefore suffice in this discussion, and these are entered in the next column. The characteristic can be almost dispensed

t	$1122\,u$	$\log 11{\cdot}22\,u$	$-\log u$	$A=\dfrac{-\log u}{t}$	$t'=t-20$	$-\log u'$	$1000\,A'=1000\times\dfrac{-\log u'}{t'}$	e = differences from the mean.	e^2
0	1122	1·050							
5	1072	1·030	·020	·0040					
10	942	·974	·076	·0076					
15	880	·944	·106	·00707					
20	820	·914	·136	·00680					
25	760	·881	·169	·00676	5	·033	[6·6]		
30	740	·869	·181	·00603	10	·045	4·50	·00	·0000
35	700	·845	·205	·00586	15	·069	4·60	+·10	·0100
40	665	·823	·227	·00567	20	·091	4·55	+·05	·0025
45	620	·792	·258	·00573	25	·112	4·48	—·02	·0004
50	580	·763	·287	·00574	30	·151	5·03	+·53	·2809
60	534	·727	·223	·00538	40	·187	4·67	+·17	·0289
65	526	·721	·329	·00506	45	·193	4·29	—·21	·0441
70	498	·697	·353	·00504	50	·217	4·34	—·16	·0256
75	420	·623	·427	·00569	55	·291	[5·29]	......	......
80	424	·627	·423	·00529	60	·287	4·78	+·28	·0784
85	420	·623	·427	·00502	65	·291	4·48	—·02	·0004
90	410	·613	·437	·00486	70	·301	4·30	—·20	·0400
95	400	·602	·448	·00472	75	·312	4·16	—·34	·1156
100	348	·542	·508	·00508	80	·372	4·65	+·15	·0225
105	340	·531	·519	·00494	85	·383	4·51	+·01	·0001
110	320	·505	·545	·00495	90	·409	4·54	+·04	·0016
115	300	·477	·573	·00498	95	·437	4·60	+·10	·0100
120	280	·447	·603	·00502	100	·467	4·67	+·17	·0289
145	250	·398	·652	·00450	125	·516	4·13	—·37	·1369
150	232	·365	·685	·00457	130	·549	4·22	—·28	·0784
							Mean=4·50		Sum=·9052

with by first dividing the numbers in column 2 by 100; accordingly, column 3 contains "log 11·22 u," instead of log 1122 u. The values for "—log u" are next found and entered, by subtracting the log 11·22 u from log 11·22 = 1·050. In practice, the latter number should be written upon the corner of a card and placed immediately above each subtrahend

*The tables of 4-place logarithms and anti-logarithms, published by C. W. Sever, Cambridge, and mounted on cardboard, are most convenient for this work.

in succession, while the remainder is written at the right. This simple device may seem too obvious to require mention. Finally, these negative logarithms (which are really positive quantities) are divided by t to give the quotients written under A. In dividing by 35, 45, etc., it may be most convenient to employ short division, using a bit of paper upon which the quotient by 5 is first written. This number is next divided by 7, 9, etc., the second quotient being written directly in its place. To avoid the needless writing of ciphers, however, between the decimal point and the significant figures, these quotients might be multiplied by 100 or 1000 before recording them, this modification being also indicated in the heading. This is illustrated in the second part of the table.

Now a simple inspection of the fifth column shows that the quantity which we have called $A = \frac{-\log u}{t}$ can by no means be regarded as a constant, and yet there is a tendency toward a pretty regular decrease in value throughout the column. There is manifestly some meaning in this fact, notwithstanding several exceptions to the general result. An experimenter, on applying this criterion, should at once seek either for some error in his process or for some important modification of his theory of the reaction. In response to an inquiry upon this point, Dr. Urech kindly informed me that the heat developed on mixing the re-agents was so considerable as to accelerate the action at the beginning of the experiment. Having thus secured a key to the discrepancy, it is easy to omit the first portion of the series, and apply the same criterion to the other observations. This is done in the second part of the table. The column marked t' denotes the interval of chemical action, *after the first twenty minutes*, to each subsequent observation. The numbers under "1122 u" must be understood as equal to 820 u', where u' is the quantity of sucrose present at any moment, referred to the quantity present at the end of twenty minutes as unity. The values of $-\log u'$ are found by subtracting the corresponding value of $\log 11{\cdot}22\ u$ from $\log 8{\cdot}20 = {\cdot}914$; the numbers in the next column are obtained by dividing by t' and shifting the decimal point, as already explained. These numbers present an approximate uniformity, which is in remarkable contrast to the column $A = \frac{-\log u}{t}$. The first value, which is excessive, may be rejected; for the combined errors of two observations must make the determination for so short an interval quite untrustworthy. The value obtained for the interval of fifty-five minutes is also excessive; an inspection of column 1122 u shows that the corresponding observation was probably affected by

some actual mistake, and it may well be rejected. The mean of the other nineteen values is 4·50; the differences or errors are written in the next column. It will now be seen that the positive errors preponderate toward the beginning and the end of the series, while negative errors accumulate toward the middle. There is no marked gradation of errors, however, and these results must be considered as a valuable confirmation of the fundamental theory of the action of mass.

Finally, the probable error, as deduced from these nineteen observations, is

$$\frac{\cdot 67\sqrt{\Sigma e^2}}{19}=\frac{\cdot 67\sqrt{\cdot 9052}}{19}=0\cdot 034$$

$$\text{Hence, } 1000\ A'=4\cdot 50\pm 0\cdot 034=4\cdot 50\ (1\pm 0\cdot 0075)$$

$$A'=\frac{-\log u'}{t}=0\cdot 00450\ (1\pm 0\cdot 0075)$$

$$a=\frac{-\log_e u'}{t}=\frac{A'}{\cdot 4343}=0\cdot 01036\ (1\pm 0\cdot 0075)$$

This result means that under the conditions of this experiment, the cane sugar present at any moment was being inverted at a probable rate of 0·01036 part of itself per minute, with a probable error of three-fourths of one per cent. of that fraction.

A more refined investigation should combine the twenty accepted readings of the polaristrobometer in some other way; for the error in the first of these readings will affect all the values obtained as above. Appropriate weights should also be assigned to the several observations. The greatest percentage error will be found when the time is short and when the speed is slowest. The last readings published in Urech's paper were not included in this discussion, because they would have relatively little value in determining the coefficient of speed.

The absolute coefficient of speed can not yet be deduced, as further data are required for this purpose.

Another communication from Dr. Urech,* under date of August 10, 1882, contains several determinations of the time required to effect the "complete inversion" of solutions of cane sugar and chlorhydric acid of varying degrees of concentration, with the following results:

Experiment.	Sugar.	HCl.	Minutes.
I.	16·35 grms.	1 part.	1380
II.	8·175 "	1 "	960
III.	4·085 "	1 "	540
IV.	16·35 "	4 "	160

*Ber. d. Chem. Gesel., **15**, 2130.

These figures are quite in accordance with the theory of the action of mass, but they do not admit of satisfactory quantitative discussion. The terminal ciphers in the last column suggest the probability that no attempt was made to determine the exact minute of completed action. In fact, according to the theory, the quantity of cane sugar diminishes as the ordinate of a logarithmic curve, and absolutely complete inversion (if molecules were infinitely small) would take an infinite length of time. We must, therefore, consider the time found in each experiment, as *the period necessary to reduce the cane sugar to a quantity too small to be detected under the conditions of the experiment.* One who is a stranger to the experimental details would not even be justified in assuming that the quantity remaining at the close of these experiments was constant; hence, all these determinations may be regarded as *qualitative*, so far as the mathematical discussion is concerned. More satisfactory results were obtained later.

Dr. Urech informed me (by private letter of September 23) that he has repeated his experiments, under improved conditions, with more accurate results. The following abstract is freely translated, with some abridgment.

"The general results are as follows:

"1. The inversion of sucrose by HCl + aq. is a complete (or unlimited) reaction.

"2. The time required for inversion, with various proportions of sucrose, water, and acid, is shorter as the temperature is higher.

"3. The time is also diminished by increasing the volume or the concentration of the aqueous chlorhydric acid used.

"4. The inversion is an exothermic reaction.

"5. The speed of the reaction at each moment (in the absence of disturbing causes, as the heat of the chemical action) is proportional to the total quantity of sucrose present."*

"I obtained the best results volumetrically, with Fehling's solution. Portions were withdrawn from time to time, and the reaction was arrested as quickly as possible by neutralizing with excess of soda. When the acid sugar solution is poured into excess of alkali (and not the reverse), the considerable heat of neutralization does not increase the extent of the inversion. When the inversion has thus been arrested in all the portions

*This proposition is equivalent to equation (1), by the aid of which the earlier determinations are discussed above.

to be titrated, the somewhat tedious determinations can be made carefully and without haste. The polariscopic process is less troublesome; but the apparatus must be provided with means for regulating the temperature, and must allow an almost instantaneous observation.

"The following are the results of two series of experiments for like concentration at about 20° C.

I. VOLUMETRIC ESTIMATION.

After 2·25	minutes,	91	per cent.	sucrose	remained.
" 7	"	74·1	"	"	"
" 17	"	46·36	"	"	"
" 32	"	24·94	"	"	"

II. POLARISCOPIC ESTIMATION, REDUCED TO PER CENTS BY LANDOLT'S FORMULA.

After 5	minutes,	70·78	per cent.	sucrose	remained.
" 10	"	57·14	"	"	"
" 20	"	37·64	"	"	"
" 25	"	29·67	"	"	"
" 30	"	26·51	"	"	"
" 35	"	19·50	"	"	"
" 40	"	11·40	"	"	"
" 45	"	9·20	"	"	"
" 55	"	4·53	"	"	"
" 65	"	2·33	"	"	"
" 85	"	0	"	"	"

"I am now determining the speed of reduction of Fehling's solution by invert sugar.* At 16° C., with five times the theoretical quantity of sugar, the copper is entirely reduced in about two hours."

The values of A and *a*, as deduced from Urech's several observations, are as follows, the initial quantity of sucrose being taken as unity:

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* Further details have just been published in Ber. d. chem. Gesel. **15**, 2687. Dr. Urech finds that the speed of reduction is influenced by the form (or size) of the vessel, a thin layer at the bottom of a large beaker being more slowly reduced than a deeper layer in a smaller beaker. This is attributed to the more rapid escape of the heat of the reaction in the former case; but it is probable that the oxygen of the superincumbent atmosphere retards the reaction in a cold solution, especially when a large surface is exposed to a large volume of air.

SERIES I.

t	u	Mantissa of log u	—log u	A
2·25	·91	·9590	·0410	·01822
7	·741	·8698	·1302	·01860
17	·4636	·6661	·3339	·01964
32	·2494	·3969	·6031	·01885
				Mean=·01883

SERIES II.

5	·7078	·8499	·1501	·0300
10	·5714	·7569	·2431	·0243
20	·3764	·5756	·4244	·0212
25	·2967	·4723	·5277	·0211
30	·2651	·4234	·5766	·0192
35	·1950	·2900	·7100	·0203
40	·1140	·0569	·9431	·0236
45	·0920	·9638	1·0362	·0230
55	·0453	·6561	1·3439	·0244
65	·0233	·3674	1·6326	·0251
85	·00		∞	∞

The mean coefficient of speed from Series I is

$$a=\frac{\cdot 01883}{\cdot 4343}=\cdot 04336$$

According to the formulæ given above, each value thus found for A expresses an independent determination of 0·4343 times the speed of the reaction under initial conditions.* Thus the mean value for Series I would indicate that under the conditions of the experiment, with whatever quantity of sucrose present, the speed of inversion would be 0·04336 of this amount per minute.

The inevitable errors of observation will make some of these determinations less trustworthy than others. All the observations quoted above, that were taken after the first thirty or forty minutes, are entitled to less confidence than those which precede; for, as the value of u diminishes, a small error will represent a relatively large error in its logarithm, and in

*It should be stated, to avoid confusion, that the term "initial velocity" (Anfangsgeschwindigkeit) is used by Menschutkin to denote the progress of the reaction during the first hour. See Ber. d. Chem. Gesel., **10**, 1728, 1898; Ann. Chem., **195**, 334, and **197**, 193, and many later papers.

the calculated value of A. At the beginning of the series, on the other hand, a small absolute error in the measurement of time will most seriously affect the result. An accurate measurement of the interval allowed is not so simple a matter as it would seem; for some time is required, both for mixing the re-agents and to arrest the action; and while the mixture is non-homogeneous the reaction is proceeding at an abnormal speed.

The values of A, as calculated from Series II, are seen to diminish rapidly for the earlier observations, and to increase rapidly towards the end. The 3d, 4th, 5th, and 6th values agree tolerably well; their mean is 0·02045, or nearly 9 per cent. more than the mean of Series I. The criterion of the preceding paper (pp. 166–167) would indicate the probability of two sources of systematic error; this series may therefore be rejected. The calculation is given in full in the table, to illustrate the facility of this method of computation. It is desirable that each observer of the speed of chemical action should apply any available criterion to his own observations, and indicate what he considers his most probable values.

The last observation of Series II, as interpreted by the formula, would give an infinite value to the initial speed. This result is by no means surprising; for the formula implies that with any finite initial speed, the reaction can not be completed in a finite period. We must suppose that sucrose was still present after an interval of eighty-five minutes, but in too small quantity to be detected. In fact, as already indicated, observation of the time required for a chemical action to be completed can not be regarded as an actual quantitative determination, though it may have a certain practical value.

Additional series of experiments are recorded and discussed in Dr. Urech's later paper (Ber. d. chem. Gesel., **15**, 2457) which give us more definite information concerning the influence of the temperature, and the quantity of acid. To calculate the constant of speed, Dr. Urech considers the conditions as remaining nearly constant during each interval between successive determinations, and he compares the mean rate of inversion during that interval with the quantity of sucrose present at the beginning of the interval. For example, between the last two determinations quoted in Series I. (page 174), the value of u was diminished from 0·4636 to 0·2494 in 15 minutes. This represents a mean decrease of

$$\frac{0{\cdot}4636-0{\cdot}2494}{0{\cdot}4636\times 15}=0{\cdot}0315$$

of the initial quantity, per minute. If we compare the decrease with half the sum of the initial and final quantities present, we obtain

$$\frac{0{\cdot}4636-0{\cdot}2494}{\tfrac{1}{2}\,(0{\cdot}4636+0{\cdot}2494)\times 15}=0{\cdot}0394;$$

while by the logarithmic formula, the required coefficient, as deduced from these two observations, is

$$\frac{\log 0{\cdot}4636-\log 0{\cdot}2494}{0{\cdot}4343\times 15}=0{\cdot}0413,$$

showing that either arithmetical method gives too low a result.* This is an extreme case; for the value of u is diminished 46·2 per cent. during the interval. In Dr. Urech's published tables, the longer intervals usually correspond to the lower values of the coefficient; for in these cases the error in the method of calculation is greatest.

No. 1, below, is the same as Series I, of page 174; but No. 2 is different from Series II. No. 1 and 3 were determined volumetrically; No. 2 and 4 with polaristrobometer.

	1.	2.	3.	4.
Sucrose taken, grams, per 100 c.c.	4·1	4·1	4·1	16·35
HCl " " " " "	11·25	11·25	11·25	0·14
Temperature, Centigrade, about	20°	21°	14°	14°
Unit of time..........................	1 min.	1 min.	5 min.	12 hours.
Urech's mean coefficient..........	0·036	0·0422	0·0792	0·0724
Ditto, calculated with one minute as the unit of time.............	0·036	0·0422	0·01584	0.0001006
Coefficient, recalculated by logarithmic formula, with one minute as the unit of time.........	0·04336	0·0440	0·01722	0·0001057

No. 2 has a relatively large probable error, and will not be considered further at present.

A comparison of No. 1 and 3 shows that the speed at 20°C. is 2½ times greater than it is at 14°C. It may be shown easily, by interpolation, from my determinations of the speed of saponification of ethyl acetate†, that this reaction takes place 1½ times faster at 20° than at 14°. The well-known viscosity of a cold solution of sugar may easily account for the relatively great difference of speed observed by Dr. Urech within these limits of temperature.

Since the quantity of HCl present in a unit of the mixture is constant during any series of determinations, the only quantitative data for the

* This necessarily follows from the nature of the logarithmic curve, which is convex toward the axis.

†Amer. Chem. Jour., **3**, 340, and Ber. d. chem. Gesel., **14**, 1361.

influence of the mass of HCl are in No. 3 and 4. A normal solution of HCl would contain 3·65 grms. per 100 c. c. Hence, according to the current theory, we should deduce the coefficient for a normal solution as follows:

$$\text{From No. 3, } 0{\cdot}01722 \times \frac{3{\cdot}65}{11{\cdot}25} = 0{\cdot}00559$$

$$\text{and from No. 4, } 0{\cdot}0001057 \times \frac{3{\cdot}65}{0{\cdot}14} = 0{\cdot}00275.$$

These results can not be accepted as a distinct confirmation of the theory; yet there is so great a difference in the conditions of the two series, that close agreement could not be expected. No. 4 had a greater amount of sugar, and the increased viscosity may have retarded the action, as in the experiments of Lunge* and of Dunn†, with glycerine, gum, etc. Although the sucrose is diminished in the course of the reaction, the total quantity of sugars (perhaps also the viscosity) remains nearly constant. Unless there is some *change* of viscosity *during the reaction*, this would not appear as a cause of disturbance on applying my criterion to any single series of observations.

No. 3 had eighty times as much HCl as No. 4. The discrepancy in the calculated normal coefficients, if not caused by the difference in viscosity, warrants a strong suspicion that an important modification of the law of action of mass, in the influence of HCl, is awaiting investigation. Experiments I and IV (page 171) are in harmony with this supposition.

The reaction which Dr. Urech has chosen has one great practical advantage; for the series of observations with polaristrobometer may be made after the mixing of the re-agents is completed, and withoutt he necessity of arresting the action; the *time measurement*, therefore, admits of great accuracy, and various usual sources of error can be completely avoided. The calculation is facilitated by having observations at equal intervals; but if, with the higher speeds, greater exactness can be secured by making the observations at irregular intervals (noting the exact instant that the interference bands disappear), the increased labor of the calculation is of no moment.

We may await further data with interest. The relations of temperature and speed will doubtless be dependent, in part, upon the viscosity of the colder solutions. The same cause may result in a diminished coefficient of speed for more highly concentrated solutions of sugar. Attention to the

*Ber. d. chem. Gesel., **9**, 1315; Jahresb. d. Chem., 1876, 13.

†Chem. News, **36**, 88; Jahresb. d. Chem., 1877, 30.

hint already secured, in regard to the influence of the acid, may yield a rich reward in advancing the theory of inversion; for if the speed is not a linear function of the acid present, we may find that the combined influence of two HCl molecules, at the same moment, is more than twice as effective as the influence of one.

XXII.—THE AURORA BOREALIS OF APRIL 16, 1882.

By Chas. G. Boerner.

[Read before the Department of Science and Arts, June 13, 1882.]

The following observations of a brilliant Aurora Borealis were made at Vevay, Indiana, on Sunday evening, April 16th, 1882. Latitude, 38° 46′; Longitude, 84° 59′ 20·5″; height above sea level, 525 feet.

April 16th, 8 P. M. A delicate rosy tint overspread the sky around the northern horizon, gradually extending east and west of north.

8 h. 20 m. The sky assumes a deep hue of rich crimson, moving from north to east and expanding beyond the zenith, glowing with pulsations at intervals of one to two seconds.

9 h. 0 m. Faint luminous streamers radiated from the north, attaining an altitude of 45°.

10 h. 0 m. One great central beam reaching beyond the zenith; others of lesser dimensions shooting up irregularly.

10 h. 30 m. The crimson tint becoming paler, retaining a rosy hue at the upper extremity; the streamers now became more numerous; also patches of nebulous light, irregular in form, appeared 10° to 15° above the horizon, west of north.

11 h. 30 m. The sky from northeast to northwest was overspread with a diffuse white light, resembling evening twilight, and of sufficient density to obscure the constellations, except stars of the 1st and 2d magnitudes; faint streamers rising 70° high; no marked change occurred until after midnight.

April 17th, 0 h. 45 m. Brilliant streamers and luminous waves of light rolled up from the horizon in rapid succession, while the eastern section again assumed its former crimson hue.

0 h. 52 m. Nebulous waves of light east of north, chasing each other at intervals of half a second.

1 h. 3 m. This seemed to be the time of greatest intensity, bright nebulous patches of white light, in contorted shape, about half a degree

in diameter, most frequent in the northwest section; the magnetic needle was in constant agitation, and deflected 25′ to 30′ eastward.

Barometer (corrected for temperature and elevation) 30·23 in.; thermometer 40°; wind northeast, velocity four miles.

1 h. 7 m. Streamers and nebulous waves continued to shoot toward the zenith from all sections of the arch.

1 h. 10 m. Diffuse white light edged with delicate crimson; bright flashing luminous waves, confined to a zone of 20° to 30°.

1 h. 15 m. Dark circular segment, surmounted by a white well defined luminous belt, about 10° in width; streamers and nebulous waves appeared without intermission, but of a more tremulous character.

1 h. 20 m. Waves and beams still rising up to the zenith but with less energy, displaying a loss of intensity and a gradual diminution of light.

2 h. 0 m. Light receding from the zenith, streamers less numerous, waves more faint and at longer intervals.

2 h. 30 m. Aurora still visible, but with greatly diminished brilliancy and absence of noteworthy characteristics.

Vevay, Ind., April 19th, 1882.

CONTRIBUTIONS TO THE LIBRARY.

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Massachusetts Institute of Technology: 17th Annual Catalogue, 1881–2; List of Publications, 1862–81; Proceedings of the Society of Arts for the Twentieth Year, 1881–2.
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Rome: R. Università Romana, Scuola d' Applicazione per gl' Ingegneri,—Annuario per 1882–3.
Royal Society of Edinburgh: Proceedings, 1880–81.
Rutgers College: Catalogue, 1882–83; 17th Annual Report of Scientific School.
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Coal, two numbers.
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The Electrician (of New York)—Monthly.
The Mining Review—weekly.
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The Student—monthly.

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BOLTON, H. CARRINGTON.—Chemical Literature.
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WRIGHT, FREDERICK G.—Studies in Science and Religion.

Unclassified.

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" Young Men's Christian Association, Buffalo, N.Y.: Forty-sixth Annual Report.

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VOL. II. MARCH, 1883. NO. 1.

SCIENTIFIC PROCEEDINGS

OF THE

Ohio Mechanics' Institute.

PUBLISHING COMMITTEE.

ROBT. B. WARDER, *Editor.*

LEWIS M. HOSEA. JAS. B. STANWOOD.

OHIO MECHANICS' INSTITUTE,

DEPARTMENT OF SCIENCE AND ARTS.

CINCINNATI, OHIO.

Entered at the Post Office, at Cincinnati, O., as Second-Class Matter.

See Special Notice on Last Page of Cover.

CONTENTS.

TO CONTRIBUTORS.

Brief notes on subjects appropriate for the Institute are requested by the Editor.

Contributors of all papers are requested to place their manuscripts or abstracts in the hands of the Publishing Committee as promptly as possible.

Reprints of articles accepted for publication will be furnished to authors at cost, if due notice is given.

Contributors are responsible for any statements in their papers.

SCIENTIFIC PROCEEDINGS

OF THE

OHIO MECHANICS' INSTITUTE.

VOL. II. MARCH, 1883. NO. 1.

PROCEEDINGS OF THE DEPARTMENT OF SCIENCE AND ARTS.

Meeting of January 19, 1883.

THE Publishing Committee presented a report of their work for 1882, and of the exchanges received. For the further dissemination of useful knowledge, they offered the following:

"*Resolved*, That the Publishing Committee be authorized to accept publications of scientific, technical, or educational value, and distribute them to our correspondents as Supplements to our own Scientific Proceedings."

This matter was referred to the joint action of the Publishing and Executive Committees.*

The annual election resulted as follows: Chairman, L. M. Hosea; Recording Secretary, John B. Heich; Corresponding Secretary, A. Springer; Members of Lecture Committee, F. W. Clarke and C. B. McMeekin; Member of Publishing Committee, Robt. B. Warder.

PROCEEDINGS OF THE SECTION OF MECHANICS AND ENGINEERING.

Meeting of January 23, 1883.

MR. JAS. B. STANWOOD gave a lecture on "GOVERNORS AND FLY WHEELS."

Reports on "PUMPING ENGINES FOR PUBLIC WATER SUPPLY" were presented by John W. Hill, M. E., and followed by "REMARKS ON THE DUTY OF STEAM ENGINES," by Professor Robt. B. Warder.

A paper on "THE WASTAGE OF WATER" was presented by Mr. Thos. J. Bell.

*Announcements of such publications may be expected from time to time, on the cover.

Mr. J. P. Kilbreth also communicated the following facts relating to the "SAVING OF FUEL":

The "Steam Generator and Smoke Preventer"* has been used on engine No. 15 of the C., N. O., & T. R. R., which draws freight trains between Cincinnati and Lexington. The official statements of the railroad company show that the average quantities of coal required, per hundred miles, were as follows:

	Engine No. 15.	All other Freight Engines.
June, 1882,	65·5 bu.	105·5 bu.
July, "	75 "	106 "
August, "	71 "	109·5 "
Means,	70·5	107

These figures indicate a saving of 34 per cent. of the coal usually consumed.

PROCEEDINGS OF THE SECTION OF CHEMISTRY AND PHYSICS.

Meeting of January 18, 1883.

DR. A. SPRINGER read a paper on "A NEW NITRATE FERMENT," and exhibited specimens of it under the microscope.

Professor H. T. Eddy presented a paper on "THE VIRIAL AND ITS APPLICATION TO THE KINETIC THEORY OF GASES."

Professor Robt. B. Warder made the following suggestions on the "INFLUENCE OF PRESSURE ON THE SPEED OF CHEMICAL ACTION":

Menschutkin† has recently published his experiments on the decomposition of tertiary amyl acetate by heating in sealed tubes. At 155°C., while the pressure was gradually increased by the formation of amylene, the speed of the reaction was found to increase until about half the ether was decomposed. Menschutkin's graphical representation of the progress of the reaction has a point of inflection at this stage; this fully accords with the theory of "action of mass," if we assume that this reaction, like many others, is promoted by pressure.

If the speed of the reaction is directly proportional to the pressure (the rate increasing, per unit weight of $C_5H_{11}·O·C_2H_3O$ to be decomposed, directly with the increase of C_5H_{10} generated), we should have, in the case of a homogeneous fluid,

$$\log \frac{u_0}{m-u_0} - \log \frac{u}{m-u} = A\,t$$

where u is the quantity of ether still present at any moment, to be eventually decomposed within the limit of the reaction,

*These PROCEEDINGS, **1**, 50.

†Ber. d. chem. Gesel. **15**, 2512–2518.

u_0 is the initial value of u,
t is the time of action, and
$\frac{m-u_0}{m}$ is the ratio of the initial to the final pressure.

By making $m = 1{\cdot}01\ u_0$ and $A = 0{\cdot}04$, we obtain an equation which approximately represents Menschutkin's curve. Variations from the function expressed above may be due to the fact that the bodies were partly liquid and partly gaseous. The value found for m (on the hypothesis here stated) indicates very great pressure toward the end of the series, as might be expected.

The following officers were elected for the ensuing year: Chairman, A. Springer; Vice-Chairman, Wm. L. Dudley; Recording Secretary, Chas. S. Evans; Corresponding Secretary, Omar T. Joslin.

I.—PUMPING ENGINES FOR PUBLIC WATER SUPPLY.—No. 2.

By John W. Hill, M. E.

[The following paper embraces abstracts of two reports presented before the Section of Mechanics and Engineering, January 23, 1883. The former paper, which relates to Gaskill Compound Pumping Engines, was printed in these Proceedings, **1**, 144–162. The methods followed in these trials were similar to those already indicated; many details could, therefore, be omitted from these abstracts, without detriment. Decimals are frequently omitted, where the round numbers serve better to represent the possible accuracy of the observations; and metric equivalents are added in brackets, or in a parallel column.—Ed.]

Examples of Worthington engines have been carefully tested at Buffalo, N. Y., and at Peoria, Ill. The results are briefly given below.

BUFFALO ENGINES, SPECIFICATIONS AND GENERAL DESCRIPTION.

Diameter of two high pressure cylinders (by contract)...	38	in.	96·52	cm.
" " single piston rods for the same (measured)	4·5	"	11·43	"
" " two low pressure cylinders (by contract)...	66	"	167·64	"
" " double piston rods for the same (measured)	4	"	10·16	"
" " plunger No. 1..................................	38·12	"	96·82	"
" " " No. 2..................................	38·10	"	96·77	"
" " plunger rods..................................	5	"	12·70	"
Mean area of plunger No. 1..................................	1131·5	sq. in.	7306	cm.²
" " " " No. 2..................................	1130·4	"	7293	"
" " " both plungers..................................	1131	"	7299	"
" length of stroke (from duty trial), engine No. 1...	49·81	in.	126·5	cm.
" " " " " " " " No. 2...	49·65	"	126·1	"

The contract specifies a capacity to raise 15,000,000 U. S. standard gallons [56,780 m.³] in twenty-four hours, against a pressure of 70 pounds

per square inch. [4·922 Kg. per cm.^{2}] when working at a piston speed of 110 feet [33·52 m.] per minute.

The duty specified was to raise 70,000,000 pounds of water one foot high with the consumption of 100 pounds of coal, estimating one pound of coal for the evaporation of ten pounds of water by the boilers.

[The required capacity is nearly 59,000 m.^{3} at piston speed of 35 m. The required duty is 21,336 Kg. m., per Kg. of net steam used.]

The steam cylinders and the heads of the low pressure cylinders are steam jacketed, the condensation being trapped from the jackets into a collecting well, into which the overflow from the condenser is also delivered, and from which the feed for the boilers is pumped.

The engine showed an unusual degree of care in every detail; in solidity and exactness of construction it is unexcelled.

Steam is furnished by two boilers of the marine fire-box pattern, with two furnaces to each. The total heating surface is about 3,500 sq. feet [325 m.^{2}], and grate surface 87 sq. feet [8·1 m.^{2}], or 2·5 per cent. of the heating surface. Lehigh coal of inferior quality was used.

CAPACITY TRIAL.

The boilers proved inadequate to the demands of the engine, for it was found impossible to maintain the contract steam pressure of 60 pounds [4·219 Kg. per cm.^{2}] under the specified working conditions. It was deemed advisable to comply with the water pressure required, even with a reduced delivery, by a diminished piston speed.

The water delivered was measured in Prospect reservoir. The vertical rise of surface levels in the reservoir were read from a measured rod, divided into feet and twentieths, which was carefully fixed and leveled. The rise of water level agreed upon was five feet [1·524 m.]; within this vertical range, accurate measurements of the reservoir were taken by Louis H. Knapp, C. E.

During the capacity trial the levels and the engine counters were read at the end of each quarter-hour; but the time that the water level reached each of the extreme points was read to seconds from an accurate watch, while counter readings were taken in the pump house at the end of every minute. In this manner the counter readings for the initial and final moments of the trial could be determined by interpolation.

The length of the trial was 5 hours, 45 minutes, 8 seconds, equal to 345·13 minutes, during which 3,523,628 U.S. standard gallons [13,338 m.^{3}] were discharged into the reservoir, corresponding to a daily delivery of 14,701,635 gallons [55,652 m.^{3}].

The number of double strokes for each engine during the trial was 3904·6, corresponding to a mean piston speed of 93·772 feet [28·58 m.] per minute.

The calculated displacement for each single stroke is

244·00 gal.	[0·9236 m.³]	for pump	No. 1, and
242·96 "	[0·9197 "]	" "	No. 2, or
486·96 "	[1·8233 "]	"	both pumps.

For 3904·6 double strokes, as made during the trial, the pump displacement would be 3,802,799 gallons [14,395 m.³], implying a slip of 7·34 per cent. of the calculated delivery. This great loss of action is surprising; but careful experiments before and after the capacity trial showed no leakage in walls or stop-valves, and a careful comparison of the data at reservoir and pump-house, by half-hourly intervals during the capacity trial, fails to suggest any unusual cause.

The corresponding values of daily service for the contract piston speed of 110 feet per second would be 17,246,938 gallons [65,284 m.³] actually delivered.

The average steam pressure in engine room was 52·48 pounds per sq. inch [3·690 Kg. per cm.²], and the water pressure gauge indicated 69·86 pounds [4·912 Kg. per cm.²]. The water pressure corresponding to a continuous contract steam pressure of 60 pounds [4·219 Kg. per cm.²] would be

$$\frac{69{\cdot}86 \times 60}{52{\cdot}48} = 79{\cdot}87 \text{ pounds } [5{\cdot}616 \text{ Kg. per cm.}^2].$$

The required delivery of 15,000,000 gallons, against a pressure of 70 pounds [4·922 Kg. per cm.²], may be had with ease by adding one more boiler to the present pair.

DUTY TRIAL.

The actual quantity of coal consumed is eliminated from the required duty equation, in which the coal to be charged is one-tenth the weight of the net steam furnished.

The water was taken from the hot well to the boilers by a donkey pump (using steam from the south battery of boilers) and carefully weighed in two large casks, mounted upon platform scales, from which it was drawn as required into a supplementary cask, connected with the suction of the feed pump.

The steam for the pumping engines was taken from the north battery of boilers only; samples were drawn from time to time for calorimeter tests.

Pressures and Temperatures.

Mean steam pressure at boiler..........	61·44 lbs. per sq. in.	4·320 Kg. per cm.[2]
" " " " engine.........	57·67 " " "	4·055 " "
Barometer....................................	29·44 in.	74·78 cm.
Vacuum, by gauge.........................	26·91 "	68·35 "
Water pressure...............................	78·74 lbs. per sq. in.	5·536 Kg. per cm.[2]
Temperature of feed water..............	65·15° F.	18·42° C.
" " overflow................	115·74° F.	46·52° C.
" " air........................	76·79° F.	24·88° C.

Plunger Travel.

Double strokes of engines, by counter,.....	13,034		13,034	
Mean length of stroke........................	4·153	ft.	1·263	m.
Total plunger travel, both pumps............	216,521	"	65,990	"
Length of trial..................................	20	hours.	20	hrs.
Speed of plunger travel, per minute.........	90·22	ft.	27·50	m.

Calorimeter and Steam.

Mean weight of steam condensed in calorimeter,	10·208	lbs.	4·63	Kg.
" " " water heated..................	200	"	90·72	"
" initial temperature........................	77·21°	F.	25·12°	C.
" final "	130·63°	F.	54·80°	C.
" range of "	53·42°	F.	29·68°	C.
Percentage of water entrained..................	3·3		3·3	
Total water pumped into boilers	299,473	lbs.	135,837	Kg.
Deduct for leakage, 1,482·5; for calorimeter, 211·5................................	1,694	"	769	"
Water and steam delivered to engines........	297,779	"	135,068	"
Water entrained..................................	9,818	"	4,453	"
Net steam...	287,961	"	130,615	"
Conventional weight of coal to be charged..	28,796	"	13,061	"

Condensation in Jackets.

Total water condensed...........................	15,111	lbs.	6,854	Kg.
Percentage of net steam........................	5·075		5·075	

The duty, calculated by the formula

$$D = \frac{A \times P \times F \times 1000}{S},$$

where $D =$ the duty in foot-pounds,

$A =$ the mean plunger area in square inches,

$P =$ the water pressure in pounds per square inch, increased by one pound for frictional resistance of water passages,

$F =$ plunger travel in feet, and

$S =$ net steam in pounds,

would be $\dfrac{1131 \times (78{\cdot}74 + 1) \times 216{,}521 \times 1000}{287{,}961} = 67{,}812{,}170$ ft. lbs.,

which is equivalent to a duty of 20,669 Kg. m., per Kg. of steam.

If, however, the duty is to be based upon the water actually delivered (by a literal interpretation of the contract), no allowance should be made for frictional resistance, and 7·34 per cent. must be deducted for the slip, as observed in the capacity trial. The practical duty would then be

$$\frac{1131 \times 78\ 74 \times 216{,}521 \times 1000}{287{,}961} \times 0{\cdot}9266 = 62{,}046{,}000 \text{ ft. lbs.},$$

equivalent to a duty of 18,911 Kg. m., per Kg. of steam.

The diagrams taken from the steam cylinders give an indicated horse power of 499·6, with duty of 68,701,100 foot-pounds at the steam end of the engine. Hence, 1·294 per cent. of the total power developed is expended in overcoming the engine and pump friction, while 9·80 per cent. is expended from these causes, combined with the friction of the water passages and the slip of the pumps.

The engine does not comply with the guaranteed duty by either method of estimate.

The following data were also obtained, though not required for the official trials:

Total coal charged in 21 hrs., 49 min....	45,100	lbs.	20,457	Kg.
Refuse weighed back.........................	6,785	"	3,078	"
Percentage of combustible..................	84·96		84·96	
Steam per pound [Kg.] of coal, from temperature of feed water............	7·005	lbs.	7·005	Kg.
Steam per pound [Kg.] of combustible,	8·245	"	8·245	"
" " hr., per unit area of heating surface,	4·134	lbs. per sq. ft.	20·19	Kg. per m.^{2}

PEORIA ENGINES, SPECIFICATIONS AND GENERAL DESCRIPTION.

The engines are of the well-known duplex type; one pair is compound, with two high pressure steam cylinders, 14 inches [35·6 cm.] in diameter, and two low pressure steam cylinders, 25 inches [63·5 cm.] in diameter, operating two double acting plunger pumps, 14 inches [35·6 cm.] in diameter, and 151·49 sq. inches [977·3 cm.^{2}] in area of the face. The nominal length of stroke is 24 inches [61·0 cm.]. Another pair of engines is non-condensing, with cylinders 25 inches [63·5 cm.] in diameter, and with pumps and stroke as described above.

The contract requires a joint daily capacity of 5,000,000 gallons [18,926 m.^{3}] of water, under a pressure of 60 pounds per sq. inch [4·219 Kg. per cm.^{2}], with a piston speed not exceeding 120 feet [36·58 m.] per minute, and a duty of 50,000,000 foot-pounds per 100 pounds [15,240,000 Kg. m. per 100 Kg.] of anthracite coal.

CAPACITY TRIAL.

The mean plunger area is 151·49 square inches [977·3 cm.²]; hence, an aggregate displacement of 50,000,000 gallons [18,926 m.³] by the four pumps, in 24 hours, would require a piston speed of

$$\frac{5,000,000 \times 231}{4 \times 151 \cdot 49 \times 1440 \times 12} = 110 \cdot 3 \text{ ft. } [33 \cdot 62 \text{ m.}] \text{ per minute.}$$

The contract allows 120 feet per minute as the maximum piston speed; hence, the required amount may be delivered, even if the slip should reach 8·1 per cent., and it probably is only about 4 per cent. The working of the engines at this speed, however, was not attended with the ease and smoothness of action necessary to durability and long-continued use. I regard it highly imprudent to work them at this rate as a daily requirement.

DUTY TRIAL OF CONDENSING ENGINES.

Pressures and Temperatures.

Mean steam pressure at boiler.............	79·08	lbs. per sq. in.	5·560	Kg. per cm.²
" " " " engine............	77·51	" " "	5·450	" "
" vacuum in condenser..............	26·78	inches.	67·86	cm.
Water pressure..............................	69·63	lbs. per sq. in.	4·896	Kg. per cm.²
P=water pressure+allowance for friction,	70·63	" " "	4·966	" "
Mean temperature of feed water..........	39·50°	F.	4·17	C.
" " " hot well.............	118·71°	F.	48·17	C.

Plunger Travel.

Double strokes of engine, by counter,	25,404		25,404	
Mean length of single strokes.........	2·012	ft.	61·32	cm.
F=total plunger travel in both pumps,	204,417	"	62,302	m.
Length of trial.............................	18	hours.	18	hours.
Speed of plunger travel, per minute,	90·22	ft.	27·50	m.

Steam.

Percentage of water entrained.........	6		6	
Total water pumped into boilers,*....	57,432	lbs.	26,050	Kg.

* Estimated from the capacity of feed-pump and the number of strokes.

Total water entrained...................	3,446	"	1,563	"
Net saturated steam.....................	53,986	"	24,487	"
Steam per pound [or Kg.] of coal....	6·066	"	6·066	"

Coal.

Total "Lackawanna" coal charged,	8,900	"	4,037	"
Refuse weighed back.....................	1,453	"	659	"
Percentage of combustible..............	83·67		83·67	

Duty.

Duty per 100 lbs. of coal..........	24,573,665	ft. lbs.		
" " Kg. " "			7,490	Kg. m.

DUTY TRIAL OF NON-CONDENSING ENGINES.

Pressures, etc.

Mean steam pressure at boiler...............	76·41	lbs. per sq. in.	5·372	Kg. per cm.[2]
" " " " engine.............	74·92	" " "	5·268	" "
Water pressure..................................	69·00	" " "	4·851	" "
P=water pressure+allowance for friction,	70·00	" " "	4·922	" "
Mean temperature of feed water............	93·82°	F.	34·34	C.

Plunger Travel.

Double strokes of engine, by counter,	28,456		28,456	
Mean length of single strokes.........	2·039	ft.	62·15	cm.
F=total plunger travel in both pumps,	232,042	"	70,725	m.
Length of trial...........................	18	hours.	18	hours.
Speed of plunger travel, per minute,	215	ft.	65·5	m.

Steam.

Percentage of water entrained.........	5·7		5·7	
Water measured by feed-pump.........	94,314	lbs.	42,780	Kg.
Steam condensed in heating feed water,	4,532	"	2,056	"
Total water supplied to boilers.........	98,846	"	44,836	"
Water entrained............................	5,634	"	2,556	"
Net saturated steam......................	93,212	"	42,286	"
Steam per pound [or Kg.] of coal.....	6·173	"	6·173	"

Coal.

Total "Orchard Mine" coal charged,	15,100	lbs.	6,848	Kg.
Refuse weighed back.....................	2,213	"	1,004	"
Percentage of combustible..............	85·34		85·34	
Coal, estimated as "Lackawanna,"...	15,367	lbs.	6,970	Kg.

Duty.

Duty per 100 lbs. of coal..........	16,011,331	ft. lbs.		
" " Kg. " "			4,880	Kg. m.

II.—REMARKS ON THE DUTY OF STEAM ENGINES.

By Robt. B. Warder.

[Read before the Section of Mechanics and Engineering, January 23, 1883.]

For our knowledge of the practical efficiency of the various forms of engines and boilers, we are largely indebted to the costly expert tests, which are undertaken either to decide between the rival claims of competitors

in a public exhibition,* or to determine whether the conditions prescribed in a contract have been fulfilled.† Such reports are intended for relative rather than absolute results; and, however completely they may answer each particular occasion, they are often presented in such terms that the results can not readily be compared with each other, for purposes of generalization. Thus, at the Millers' International Exhibition of 1880, calorimetric tests were made to determine the relative amounts of water entrained in the trials of similar engines; but the net steam required in each case is not reported.

When the duty test of an engine is based upon the fuel alone, there is no means of distinguishing the losses in the engine from those in the boiler, boiler-setting, chimney-stack, etc.; these are often influenced by conditions that do not appear in the report. The varying calorific value of the coal and the waste in the ash-pit introduce other elements of uncertainty. The efficiency of the engine itself should, therefore, be based upon the net weight and pressure (or temperature) of the steam, as furnished at the engine, exclusive of water entrained. This is sometimes provided for in the contract by the awkward definition of "duty per hundred pounds of coal, based upon an evaporative efficiency of ten to one," or such arbitrary ratio as may be adopted. The usual phraseology is also cumbersome, in requiring eight or nine digits, where five significant figures would express the results with all the precision attainable under the usual methods of observation.

	Pressure by gauge at engine in lbs. per square inch.	Pressure in Kg. per sq. cm.	Ratio of expansion.	Duty in foot-pounds per 1,000 pounds of net steam.	Duty in kilogram-metres per Kg. of net steam.
1	81·8	5·75	[9]	[97,410,000]	[29,827]
2	81·8	5·75	[9]	[99,073,000]	[30,380]
3	74·2	5·22	[12]	107,930,000	32,896
4	93·0	6·54	7·89	90,984,000	27,731
5	92·3	6·49	9·82	98,543,000	30,034
6	57·7	4·05	3·32	67,812,000	20,669
7	77·5	5·45	[4·19]	41,458,000	12,636
8	74·9	5·27		26,398,000	8,046

*As in trials made by J. C. Hoadley, M. E., these PROCEEDINGS, 1, 54, 121, 124.

†As in trials made by John W. Hill, M. E., these PROCEEDINGS, 1, 144, and 2, 3.

The preceding table gives the practical efficiency of several pumping engines, with the steam-pressures at engine and expansion ratios. The data are taken from reports by John W. Hill, M. E., but the results are recalculated to a basis of one thousand pounds and to one kilogram of net steam, and expressed in round numbers. Values enclosed in brackets are based upon estimates, as explained in detail.

The first five are rotative, the rest are direct-acting pumping engines.

No. 1 and 2 are the Memphis engines, described in these PROCEEDINGS, **1**, 145–155. No indicator diagrams were tabulated, and the expansion ratio was simply estimated by Mr. Hill. The amount of steam used was not determined, but as the best Lehigh coal was burned, Mr. Hill estimates an evaporating efficiency of ten to one; and I have accordingly placed the published duty in the table. As there was an allowance of two pounds per square inch for frictional resistance, these values should be diminished one and three-tenths per cent., to reduce them to the usual basis.

No. 3 is the Saratoga engine (these PROCEEDINGS, **1**, 155–162), for which the ratio of expansion is estimated at twelve or more. The Lackawanna coal used yielded 10·457 times its weight of net steam.

No. 4 and 5 are the Gaskill compound engines, tested by Mr. Hill at Evansville, Ind.

No. 6, 7, and 8 are the Buffalo and Peoria engines, discussed in the foregoing paper (pages 3–9). The duty of the Peoria engines, by the terms of contract, was based upon the consumption of anthracite coal, which yielded little more than six times its weight of net steam. The expansion ratio for No. 7 is by volume, from measurements of the cylinders. No. 8 was non-condensing.

The table serves to illustrate the practical as well as theoretical advantage of a high grade of expansion. Yet direct-acting pumps are deservedly popular from their simplicity and their economy in first cost and repairs. It is a question for the inventor to consider, whether some regulating device, less costly than the fly-wheel and its accessories, can be applied to receive energy during the first part of the stroke and impart it during the last part, thus enabling a lower terminal pressure in the cylinder to complete the stroke against a given water-pressure. With such device, a higher ratio of expansion with higher duty may be obtained with direct-acting pumping engines.

III.—THE PRESERVATION OF WOOD FROM DECAY.

By F. W. Clarke.

[Read before the American Forestry Congress, April, 1882. For the action taken by the Department of Science and Arts, see these Proceedings, 1, 101-102.]

That the protection of wood from decay is one of the most important of industrial problems can hardly be denied; and yet in this country it has scarcely begun to receive proper attention. Our forests are rapidly wasting away, the price of wood is continually increasing, its applications are becoming more and more numerous, and still little is done. In 1855 lumber sold for about $18 per thousand, in 1860 for $24, and in 1865 for $45. Although a single acre of pine land yields on the average only about six thousand feet of timber, billions of feet are annually sold in the United States. It is estimated that the supply of white pine will be exhausted, at present rates, in about eight years. The question of preservatives will force itself upon our notice so urgently that it can not be ignored. Prudence already insists upon a more rigid economy.

In Europe, much attention has been paid to the problem—England, France, and Germany taking the lead. In Great Britain alone not less than fifty patents for the preservation of wood have been taken out during the present century. To be sure, some patents have been granted at Washington, also, but their value is relatively slight. What is the consequence of this trans-atlantic superiority? Simply that railway sleepers, bridge timbers, and telegraph posts last more than twice as long abroad as in America, and that all other exposed wood has similarly gained in durability. Surely this fact is worth the attention of our practical men. Mere temporary cheapness can not much longer pass for economy.

Many experiments demonstrate the advantage of protecting wood by chemical means. Prepared and unprepared timbers have been exposed together, and the overwhelming superiority of the former proved. A great variety of preservative methods have been found practicable, but an attempt to decide upon their relative merits is quite difficult. The material for criticism is bulky enough, but deficient in quality. All the desirable details are rarely given. A process which thoroughly protects one kind of wood may utterly fail with another. One method may succeed with seasoned timber, yet be useless for preserving green wood. Accordingly we find the most contradictory statements concerning every prominent protective process. One man finds it admirable, another denounces it as worthless. In order to get at results of true

practical value, and to avoid these seeming discrepancies, we have to consider several things: first, the general efficacy of each process; secondly, the kind of wood to be used, and its condition; thirdly, the expense, both actual and comparative; and fourthly, the particular use to which the wood is to be applied. The first and second of these questions can be settled only by the evidence of actual tests. The matter of expense involves, to some extent, the subject of locality. The fourth question opens up considerations of this sort. Given two processes for preserving wood, one of which will protect for fifteen years and the other for only ten, the latter being decidedly cheaper. If, now, we are to deal with the timbers of a bridge, the first of these processes, notwithstanding its greater expense, may be the more desirable of the two. But if we are to lay down wooden pavements which will be worn out by the wear and tear of travel long before the cheaper preservative has lost its protecting power, then the latter, though the inferior process in general, is the better for our purposes. In other words, an expense which may be advantageously incurred in one case, may be wholly unadvisable in a second.

The decay of wood may be generally traced to one of three causes. It is due either to slow oxidation, to the ravages of certain minute animals, or to an action induced by contact of the fibre with the decomposing albumenoid substances of the sap. It has at times been ascribed to the growth of fungi; but as these have been found to appear only after decay has fairly commenced, this supposition may be set aside. The rapidity of the change, however, is much influenced by external circumstances. In perfectly dry places wood rots very slowly, and has been known to remain sound for hundreds of years. Completely immersed in water, except where it is exposed to the attacks of the teredo, it is similarly permanent. The piles of Old London Bridge were found to be good after having been down eight hundred years. But in damp places, or in places alternately wet and dry, especially where there are frequent and great changes of temperature, wood decays very quickly. This is the case with wooden pavements particularly. Snow, rain, sun-heat, and frost are ever at work upon them, and particles of fermenting animal matter, like horse manure, are constantly getting in between the blocks, and making the difficulty of preservation greater.

Now, leaving out of account altogether the processes of drying, washing, boiling, and steaming wood, we shall find that four distinct classes of methods for its preservation have been proposed. The first class contains all those methods which deal simply with the surface of the

wood, leaving the interior structure unprovided for. Every process of this sort consists merely in the application of some air-tight varnish to the wood, none of these varnishes being sufficiently valuable to warrant description here.* The second class of processes comprises those by which the surface of the wood is carbonized, and the layers immediately beneath are somewhat affected also. Three plans of this sort have been proposed. In the first, which has no recommendations, the wood is charred by immersion in strong sulphuric acid. The second plan is to dip the wood into mineral oil or naptha, then, after withdrawing it, to kindle its surface, and allow it momentarily to burn. The third process, and the one which has been the most thoroughly tested, is that of M. de Lapparent, as used in the dockyards of Cherbourg, Dantzic, and Pola.† A jet of flame from a specially constructed coal-oil lamp is thrown upon the surface of the wood to be preserved. The outer layer is carbonized, while the layers immediately beneath undergo a partial destructive distillation which results in the formation of antiseptic, empyreumatic substances within the wood. This method has been highly recommended for the preservation of ship timbers, but is manifestly inapplicable to cases in which numerous small pieces are to be handled, as with wooden pavements. The cost of the labor involved in carbonizing the immense surface of the necessarily small blocks would be unbearable. There is an improvement upon de Lapparent's process, due to Hugon.‡ The difference is in the construction of the lamp. The improved method has been successfully employed in France for the preservation of telegraph posts.

In the third class of processes we find all those whereby the wood may be charged with insoluble mineral substances, and so protected from change. These all depend upon the principle of double decompositions —the wood being successively impregnated with two solutions which are capable of precipitating each other. Methods of this sort were proposed by Gossier, in 1828; Treffry, in 1838; and Fliselli, in 1840. In 1837, the Industrial Society of Annaberg recommended the use of water-glass and hydrochloric acid. Ransome seems to have reiterated this suggestion, possibly with modifications, in 1845. Burkes, in 1844, proposed water-glass and sulphate of iron; and Feuchtwanger has recommended soluble glass and lime-water. In 1846, Venzat and Banner suggested

*The recipe for such a varnish may be found in Scientific American, vol. 6.

†Dingler's pol. Journal, **181**, 42. 1866.

‡Dingl. pol. Jour. **189**, 456. 1868.

the use of sulphate of copper with caustic baryta. Muller* claims to have obtained good results with sodium phosphate and barium chloride; and Schweitzer† asserts that a combination of sodium sulphate and calcium chloride has merits. But Payne's process, brought forward in 1841, has been more thoroughly tested than any other in this class. Payne tried experiments with various saline couples, but especially with a mixture of the sulphide of barium or calcium, with the sulphate of iron. Sulphide of iron and the sulphate of the earth were of course formed within the wood. The process, however, was costly and imperfect, and is now pretty much, if not altogether, abandoned. The same may be said of similar double processes. I have cited these methods only for the sake of completeness.

All the preservative processes at present in vogue belong to our fourth and last class. They depend upon the injection of various antiseptics into the wood, and vary not only with regard to the antiseptic used, but also in the method of applying it. The simplest method of application is merely to soak the wood in the preservative liquid. Almost as simple is the device of boiling the wood in the antiseptic. At one time, Boucherie recommended absorption by the living tree. Deep cuts were made in the trunk near the roots, a sort of tank built around them, and the tank filled with the solution to be used. Sometimes the tree, immediately after felling, was placed upright, with its lower end in a vat of liquid. In either case the preservative solution was drawn upward by the capillary force of the tree, and penetrated even to the leaves. According to Hyett,‡ a poplar-tree, ninety feet high, placed thus with its lower end in a solution of crude acetate (pyrolignite) of iron of sp. gr. 1·056, absorbed about ten cubic feet of the solution in six days. In a variation of this method, the preservative was applied to the top of the recently cut log, being enclosed in a kind of rubber cup. Different sorts of wood were then found to be differently penetrated. Beech absorbed the antiseptic readily, poplar with less ease, and ash scarcely at all. Heart-wood of Scotch fir, says Hyett, resisted permeation entirely. But all these methods of impregnation have been supplanted by the process which originated with Bréant, and which, adopted since by Bethell, Burnett, and Boucherie, has been made well-nigh perfect. The wood to be preserved is enclosed in a strong iron cylinder, from which the air is exhausted by means of a powerful steam pump. Then, under great pressure, the antiseptic fluid is allowed

*Sci. Amer. **25**, 328. 1871. Dingl. pol. Jour. **202**, 290. 1871.

†Dingl. pol. Jour. **125**, 121. 1852.

‡See Parnell's Applied Chemistry.

to flow in, and permeates the wood in a most complete manner. Of course, the cylinders vary in size, and different pressures are employed. The most convenient dimensions seem to be about 35 feet by 5, and the suitable pressure, about 125 pounds to the square inch.

As for the antiseptics which have been applied by these various methods to the preservation of wood, the list is very long, beginning with the recommendation of tar by Glauber, in 1657. Coal-tar, vegetable tar, creosote, petroleum, bitumen, and the so called "pyrolignite of iron," have all been employed. Rosin has been used for the protection of wooden pavements in Cleveland. Solutions of rubber in naphtha or bisulphide of carbon have been recommended, but are of course too costly. Munzing, in 1840, suggested the use of the refuse liquor of the chlorine manufacture. Tannin, extracted from peat moss, gave unsatisfactory results. An arsenical solution, obtained from arsenical pyrites, was found to be dangerous to the workmen. Lime, and the alkalies, according to Parnell, really hasten the decay of wood; lime, however, has been highly recommended by some writers, and possibly it may work very differently with different varieties of wood. The other agents which have been proposed as preservative, are common salt, sodium sulphate, borax, saltpetre, potassium dichromate, sugar of lead, zinc chloride, zinc sulphate, verdigris, copper nitrate, copper sulphate, ferric nitrate, ferrous sulphate, corrosive sublimate, and the various agents used in the process commonly known as "creosoting." This list may not be quite complete, but it is nearly so. Some of these compounds have been found ineffective, and others, as for instance borax,* have not been sufficiently tested.

The value of salt as an antiseptic is well known, but needs farther testing with reference to the preservation of wood. For this purpose it seems first to have been recommended by Volmeister, in 1798. It has some good effect, which is due partly, if not wholly, to its hygroscopic action. Examples of its efficacy may be found in many salt mines, whose timbers exhibit remarkable durability. Ships engaged in the salt trade remain sound, it is said, much longer than other vessels. But the best test of the preservative power of salt was made some time ago in Saxony.† Wood prepared with this substance was exposed side by side with some which was unprotected. The impregnated timber was perfectly sound at the end of thirteen years, while the other became unserviceable in two.

At one time, corrosive sublimate was largely in vogue, but it is at present little used on account of its high cost, and its deleterious effects upon

* Recommended by Sigismund Beer. Sci. Amer. vol. 18.

† Dingl. pol. Jour. **202**, 174. 1871.

workmen. As a preservative of wood, it seems first to have been recommended by Knowles and Davy in 1821. Kyan, whence the term "kyanizing," introduced it in 1832. In 1837 Letellier proposed to use it in connection with gelatin. The double chloride, $HgCl_2 + KCl$, (procured by the decomposition of carnallite with mercuric oxide*) has lately been used as a substitute. The corrosive sublimate is injected into the wood by steam power, the standard solution containing one pound of the salt to five gallons of water. Its value as a preservative agent is unquestionable. At Woolwich,† pieces of kyanized and unkyanized wood were buried together in a trench. This trench was filled with putrefying vegetable matter and fragments of wood affected with dry rot, the whole being covered with horse-dung. At the end of five years, the protected wood was found to be unchanged; while that which was unprepared was seriously affected in one year.

With regard to ferrous sulphate, statements disagree. It has had the tests of experience less thoroughly than some other more fashionable preservatives. It was recommended by Strutzlei in 1834, Earle in 1843, and Apelt in 1853. Bohl, whose results will be considered in another connection, has employed it simultaneously with creosote. Its mode of action is rather complex. Injected into wood, it finds enclosed there a certain quantity of atmospheric air. The oxygen of this air is soon absorbed by the ferrous sulphate, basic sulphate and some ferric oxide resulting from the change. On one hand, it is said that this action is beneficial. The fibre of the wood becomes coated with mineral matter, and is so protected from decay. In opposition, it is urged that the wood is weakened by this reaction, and that it is far less completely protected from decay than by some other more familiar processes.

Copper sulphate—blue vitriol—must pass for one of the very best of the preservatives of wood. Its merits have been tested quite thoroughly, and some occasional failures in its action have been satisfactorily explained. Boucherie, who made experiments with a number of antiseptics, after getting poor results with salts of lead and iron, finally settled upon this agent as the best of all, and time has in many respects justified his decision. At first Boucherie impregnated the wood by the process of suction, which we have already considered, but finally he adopted the cylinder of Bréant. Unfortunately, however, copper sulphate is not applicable to wood under all circumstances. Baist‡ has

* Wagner's Chemical Technology.

† Parnell's Applied Chemistry.

‡ Dingl. pol. Jour., **162**, 397. 1861.

shown that it fully protects only green wood containing much sap, and Boucherie, Jr., somewhat corroborates this statement. Kirschweger,* also, claims that freshly cut wood is best for treatment with this preservative. This may perhaps enable us to explain the failure cited by Dalpiaz,† who says that on the Paris and Rouen Railroad, the timbers of a bridge which had been prepared with copper sulphate decayed with unusual rapidity. Either the wood was in an improper condition when treated with the sulphate, or else the impregnation was not carried out conscientiously. One other point remains to be noticed. According to Koenig,‡ resinous woods retain this antiseptic better than those which are non-resinous. From the latter the sulphate may be partly, at least, washed out, while in the former it seems to be fixed by the resin, probably in the form of some basic compound. The resin itself, however, is a preservative.

The testimonials to the efficacy of copper sulphate in preserving wood are quite numerous. In some of the German mines it has been found to give even better results than the zinc chloride.|| But on certain German railways, where it had been employed for the protection of sleepers, it was found to attack the iron. On the other hand, it is said that if the sleepers be thoroughly dried after impregnation, no such objectionable result will follow. In 1855, the Jury of the French Exposition put forth an extremely favorable report concerning Boucherie's process, asserting not only its value, but also its superior cheapness over the plan of creosoting.§ In 1846, about eighty thousand sleepers saturated with copper sulphate, together with some which were unprotected, were laid down on the Northern Railway of France. In 1855, nine years afterward, the prepared sleepers were as good as ever, the others having long been decayed and replaced by new ones. For preserving telegraph posts, copper sulphate has been similarly effective. The saving to French lines alone, up to 1855, was estimated at two and a half million of francs.** Examples of this sort could easily be multiplied, but one more will suffice. In 1868, Boucherie, Jr.,** exhibited to the French Academy specimens of wood which had been prepared

* Dingl. pol. Jour., **122,** 223. 1851.
† Dingl. pol. Jour., **120,** 140. 1851.
‡ Sci. Amer., **5.** Dingl. pol. Jour., **160,** 48, 1861.
|| Dingl. pol. Jour., **202,** 174, 1871.
§ Jour. Frank. Inst., **32,** 1. 1856.
** Comptes Rendus, **67,** 713. 1868.

according to his father's process, and exposed since 1847. These specimens, after twenty-one years of exposure, were as sound, as elastic, and as strong as when new, and readily yielded the reaction of the copper they still contained.

In England and America the chloride of zinc has probably been used much more largely than any other metallic salt for the preservation of wood. Having been introduced by Burnett in 1838, its application to wood is known as "burnettizing," and the wood thus prepared is said to be "burnettized." The solution commonly employed contains one pound of the salt to ten gallons of water, and is injected by steam pressure in a cylinder like that of Bréant. The same limitations which apply to the copper sulphate seem also to hold good of the zinc chloride, the latter compound having the advantage of cheapness, and being nearly, if not quite as efficient a preservative. Burnettized wood was found to stand the Woolwich test as well as that which had been kyanized. In Germany the chloride has been applied successfully to railway sleepers, bridge timbers, and telegraph posts, and also to the wood-work in some of the Hartz mines. Furthermore, it has been successfully used for the protection of wooden pavements.

One more preservative method remains to claim our attention, namely, that of creosoting. Bethell, in 1838, using a vacuum cylinder, injected into wood a preparation of coal-tar oil, known commercially as "gallotin." Since that time, peat and brown coal creosote, paraffine, pyroligneous acid, and the so-called "pyrolignite of iron," have been applied in the same way. The best of all the substances of this class, however, is the heavy oil or "dead oil" of coal-tar. That portion is chosen which boils at about 180° C., and depends, to a great extent, for its efficacy upon the phenol which it contains. This phenol coagulates the vegetable albumen, while the bituminous oils completely penetrate the capillaries of the wood, cover the fibres with an impervious coating, and protect them entirely from the action of water and air. Bohl* finds that the poorer the liquid is in oily matter the more readily it penetrates the wood. Since much of the creosote is easily washed out, he subsequently treats the wood with ferrous sulphate, in order to fix the preservative. Ferrous hydroxide is precipitated, which is gradually converted into the ferric hydroxide at the cost of such atmospheric oxygen and moisture as may have been retained in the wood. There are two main objections to the plan of creosoting timber. The first is that it is applicable only to

*Dingl. pol. Jour., **144**, 448. 1857.

winter-cut hard woods. In this respect it is just the reverse of the copper sulphate process. The latter protects green but not seasoned wood, the former preserves seasoned but not green wood (See the paper by Baist already cited). The second objection is based upon the amount of the preservative to be used. Lumber, properly treated, absorbs about eight pounds of the coal-tar oil to the cubic foot.*

At present Bethell's process is largely used in England. For the preservation of railway sleepers it is said to be employed to the total exclusion of all other processes. On the Buckinghamshire R. R. ninety thousand kyanized, burnettized, and payneized sleepers were laid down, with thirty thousand which had been creosoted, and the last proved the most durable.* In the mines of Prussian Saxony, Upper Silesia, Thuringia, and Saarbruck, coal-tar for the protection of timber is preferred to the zinc chloride;† and in an experiment by Price, at Gloucester, England, when unprepared wood decayed in a year, kyanized wood lasted for seven, and then rotted, while creosoted specimens were as good at the end of twelve years as at first.‡ As a general process, Bethell's, including its variations, seems to be the best of all.

I subjoin a list of a few of the more important among the papers bearing upon the preservation of wood. Many other papers may easily be found by working over the files of the "Artisan," "Van Nostrand's Magazine," "The Engineer," "Engineering," "Journal of Gas Lighting," "Revue Universelle des Mines," "Annales des Mines," "Moniteur Industriel," etc. See also good articles on the subject in Wagner's "Chemical Technology," Parnell's "Applied Chemistry," and Payen's work upon Industrial Chemistry. The Annual Report of the Smithsonian Institution for 1864, page 196, contains another full paper upon the subject.

Chemical News, **19**, 148. 1869. P. M. Moir. "On the Preservation of Timber." Also in Jahresb. f. Chem., 1869, 1142.

Comptes Rendus, **67**, 713. 1868. Maurice Boucherie. "Observations relatives à la conservation des bois." Also in Dingler's pol. Jour., **191**, 330, and Jahresb., 1868, 983.

Mechanics' Magazine, **9**, 340. 1863. "Preserving Wood with Pyroligneous Acid."

Mech. Mag., **16**, 238. 1866. "On the Preservation of Wood by Carbonization." (Account of de Lapparent's Process).

Mech. Mag., **24**, 137. 1870. "On the Preservation of Timber." (A general paper).

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*Sci. Amer., **3**, 186. 1860.

†Engineering, **13**, 30. 1872.

‡Dingl. pol. Jour., **123**, 146. 1852.

Trans. Am. Soc. of Civil Engineers, **11**, 345. 1882. William P. Judson. "The Kyan Process for Preservation of Timber."

Journal Franklin Institute, **16**, 45. 1848. "List of the Different Processes adopted for the Preservation of Wood, from the year 1657 to 1846; prepared by M. J. A. Stoeckhardt."

Jour. Frank. Inst., **32**, 1 and 408. 1856. "Dr. Boucherie's Patent Process of Preserving Wood from Decay." (Report of Jury of French Exposition).

Jour. Frank. Inst., **52**, 217 and 289. 1866. H. W. Lewis. "Preservation of Wood in Damp and Wet Situations." (A general paper).

Bruxelles Acad. Sci. Bull., **15**, 424. 1863. Rottier. "Recherches sur la conservation du bois, au moyen de l'huile lourde de goudron de houille, dite huile créosotée."

Papers are printed in Scientific American, as follows:

3, 386.	1860.	Creosoting Railroad Timber.
13, 407.	1865.	Preserving Timber.
18, 145.	1868.	S. Beer's Process for Preserving Wood.
19, 213.	1868.	T.W. Heinemann. Improved Method of Preserving Wood.
20, 3.	1869.	Letter from Feuchtwanger.
29, 120.	1873.	The Use of Paints for Preserving Timber.
31, 319.	1874.	A Review of Paulet's Work.
32, 199.	1875.	Note on Moore and Weatherby's Process.
33, 265.	1875.	Note upon Rottier's Plan of Using Ammoniacal Copper Salts.
34, 259.	1876.	On Palmer's Patent.
38, 145.	1878.	On Hayford's Creosoting Process.
42, 6.	1880.	Note Concerning the Preservative Effects of Lime.

Papers may be found in abstract in Jahresbericht für Chemie, as follows:

1847–48, 1128.	Payne's Process.
1855, 901.	Durlach and Schweitzer.
1857, 647.	Vohl on Coal-Tar Oil.
1864, 810.	Melsens, and others.

The following papers are all in Dingler's polytechnisches Journal:

100, 244. 1846. Note on Ransome's Process.

101, 153. 1846. "Ueber die Conservirung des Holzes für Eisenbahnschwellen, u. s. w., nach Paynes' Verfahren."

101, 156. 1846. Note on Venzat and Banner's Method.

104, 274. 1847. "Verfahren das Holz für Eisenbahnschwellen, u. s. w., zu conserviren." (Paynes' Patent).

108, 373. 1848. Hutin and Boutigny. "Ueber das Conserviren des Bauholzes, und besonders der Eisenbahnschwellen."

109, 135. 1848. v. Gemini. "Schutzmittel gegen das Verderben des Holzes aus natürlichen Ursachen, insbesondere durch Fäulniss und Insectenfrass."

120, 140. 1851. Dalpiaz. "Ueber das Conserviren des Holzes."

122, 223. 1851. Kirschweger. "Ueber das Präpariren der Hölzer, besonders der Bahnschwellen, zum Schutz gegen Fäulniss."

123, 146. 1852. J. E. Clift. "Ueber das Conserviren des Bauholzes durch Krosot."

125, 121. 1852. Schweitzer. "Ueber Conservirung des Holzes gegen Fäulniss."

128, 392. 1853. "Die Conservirung des Holzes nach der in Königreich Sachsen patentirte Methode des Dr. Apelt."

130, 131. 1853. Lüdersdorff. "Das Conserviren des Bauholzes."

144, 448. 1856. H. Bohl. "Ueber das Conserviren des Holzes vermittelst sogenannten Kreosot (Steinkohlentheeröls), und über die Anwendung des reinen Kreosots und der Karbolsäure, wie solche bei der Photogen Fabrication gewonnen werden, zu demselben Zwecke."

160, 48. 1861. König. "Ueber die chemischen Vorgänge, welche beim Imprägniren des Holzes mit Kupfervitriol stattfinden." See also Scientific American, **5**, 197; and Jahresbericht, **14**, 932. 1861.

161, 237. 1861. H. Bohl. "Ueber das Conserviren der Nutzhölzer (Eisenbahnschwellen, Telegraphenstangen, und Schiffsbauholz), sowie das Imprägniren des Segeltuchs und der Schiffstaue, vermittelst Kreosot-Natrons."

162, 397. 1861. L. Brist. "Neue Erfahrungen über das Conserviren von Holz mittelst Kupfervitriol und Theer."

163, 306. 1862. C. Weltz. "Wie ist die Beobachtung zu erklären, dass mit Kupfervitriol imprägnirtes Holz der Fäulniss länger widersteht, als nicht imprägnirtes?"

167, 312. 1863. F. Liesching. "Ueber die Behandlung des Nutzholzes zum Zwecke besserer Conservirung."

181, 42. 1866. "Ueber das oberflächliche Verkolen des Holzes (insbesondere der Telegraphenstangen) nach dem Verfahren von de Lapparent."

189, 456. 1868. "Ueber Hugon's Apparate zur Conservirung des Holzes durch Ankohlen mittelst einer Löthrohrflamme und zum Zertrennen harter Felsarten; Bericht von Payen."

189, 184. 1868. "Ueber Beer's Verfahren zum Conserviren von Holz." See also Scientific American, **18**, 145.

202, 174. 1871. "Ueber Imprägnirung des Grubenholzes."

202, 390. 1871. Armand Müller. "Ueber Barium Phosphat zum Conserviren von Holz." Also Scientific American, **25**, 328.

Other papers and various notes may be found in **79**, 467; **80**, 192, 194, and 196; **84**, 74; **85**, 396; **86**, 434 and 439; **87**, 397; **88**, 76 and 319; **91**, 363; **93**, 66; **94**, 443; **97**, 80 and 423; **99**, 56; **161**, 464; **178**, 416; **210**, 77; **211**, 480; **212**, 529; **213**, 360; **214**, 251; **215**, 287 and 471; **218**, 370; **221**, 186; **228**, 189.

IV.—A NEW NITRATE FERMENT.

By A. Springer, Ph. D.

[Read before the Section of Chemistry and Physics, January 18, 1883.]

The importance of any discovery which tends to further our knowledge of the transformations of the nitrogenous compounds of the soil, before and after assimilation by plants, can not be overestimated; espe-

cially if we keep in mind Lawes and Gilbert's theory: "First, fertility is not proportionate to the amounts of available ash constituents in land; second, the efficacy of manure is not proportionate to the amounts of ash constituents it contains; third, the exhaustion of land in the ordinary practice of agriculture consists chiefly more in the accumulation of nitrogenous and carbonaceous food materials in the farm-yard manure than in the difference between the ash constituents taken from the land by corn and fallow crops; and fourth, the requirements of cultivated plants can not be measured merely by results of analysis."

Nitrogen is an essential element in the food of plants. Though the quantity of it present in the seed may serve in many cases for the purposes of nutrition until the plant has arrived at considerable bulk and accumulated a large stock of carbon compounds, a limit is at last reached; without a further supply of nitrogen, no further growth can take place. Therefore we can easily understand the importance of the turnip as fallow crop, and of leguminous plants, when we bear in mind that they possess the power of assimilating nitrogen from the atmosphere.

Many theories explanatory of nitrification have been suggested, but their fallacy has been shown sooner or later. At last, the theory that it is due to the work of a living organism in the soil has thrown new light upon the subject. The first suggestion of the possibility of such an explanation was made by Pasteur in 1862, but to Schlösing and Müntz belongs the credit of establishing this hypothesis by experiment. They found that sewage might be slowly filtered through a porous column of pure sand and limestone without nitrification at first taking place. After twenty days nitrification set in, and the ammonia of sewage was, after this time, entirely converted into nitric acid. A porous medium is not absolutely necessary for nitrification; sewage, or a weak solution containing ammonium salts, sugar, and cinereal matter, may be nitrified by passing over polished pebbles, if a little vegetable earth be added as seed. Schlösing and Müntz described the organism which acts as the nitrifying ferment as consisting of extremely minute round or slightly elongated corpuscles, existing either singly or joined in couples; it is of slow growth, and multiplies apparently by budding. There is but little doubt that nitrification is owing to the presence of these organisms, which have the power of converting nitrogenous compounds into an assimilable form.

The next question which naturally arises is this: After the nitrogenous compounds have served their various functions in the plant, how are they again reduced? I believe I have succeeded in proving that this

transformation, also, is due to the presence of a living organism. A year and a half ago, while experimenting with infusions of the roots of plants in water, I noticed a copious evolution of nitric oxide, proceeding from those rich in nitrates, and it immediately struck me that this arose from the action of small organisms which covered the roots of plants. I then made separate infusions of the roots, stems, and leaves of tobacco, and divided each set into four parts. Fermentation was excited in the first by the addition of a small quantity of yeast, in the second by urine, in the third by the so-called spontaneous method, and in the last by the addition of the newly discovered ferment, obtained by successive cultivations. Not only were the nitrates originally present dissociated, but also considerable quantities of freshly added nitrates underwent the same process. All the infusions contained, among other ferments, one special kind, noticeable by its extreme activity. In appearance it closely resembles the butyric ferment, being composed of small cylindrical rods rounded at the extremities, generally isolated, or, when joined two by two, acting as one body. They move rapidly across the field of the microscope with a wriggling motion, and often bend their bodies until they form a perfect circle. Another ferment or modification of the former, though somewhat smaller, is also present, which spins around its smaller diameter. Phenol has no appreciable effect on the new ferment, and serves partially to isolate it from others. Believing that to this ferment is due the property of dissociating the nitrates of the soil, I have begun a series of experiments in that direction.

I give these preliminary statements in regard to my work on account of the experiments lately made in France by Gayon and Dupetit, and by Dehérain and Maquenne, the results of which closely agree with mine, as stated in this Institute a year ago. Like the above-mentioned chemists, I also obtained butyric acid. There is but little doubt that the ferment mentioned by Bechamp,* when working with chalk from cretaceous formations, instead of pure precipitated calcium carbonate, and by him called Microzyma cretæ, is the one obtained by me from plant infusions. Perhaps the conflicting accounts of butyric ferments are often owing to the presence of this widely-spread ferment. Although it may be classed among the Anaerobies, oxygen does not kill it or stun it for any length of time. Temperatures between 35° C. and 40° C., and much water, are most propitious for its activity.

The ferments are most abundant on the roots, less on the stems, and

*Bull. soc. chim. [2] 6, 484.

least on the leaves of plants rich in nitrogenous compounds; hence, I am led to believe that there may be some bond between them and the assimilation of nitrogen. In order to test this hypothesis, I have now in my laboratory, soil first heated to 120° C., whereby the organisms are destroyed, and placed in bottles supplied with air filtered through cotton. In some of the bottles, well-washed seeds and plants are sown and the ferment is added; in others, its presence is avoided.

Bibliographical Note on the Preceding Paper.

BY ROBT. B. WARDER.

The following papers relate to the germ theory of the oxidation and reduction of nitrogenous compounds. The list does not pretend to be complete, but it may aid those who desire to examine this subject. See also Warrington's article on "Nitrification," in Watts' Dictionary of Chemistry, third Supplement, pages 1400–1403.

A. Müller. Offic. Ber. über Reinigung u. Entwässerung Berlins, Heft XII., 605, 616; and Landw. Vers.-Stat., **16** (about the year 1873).

Ber. d. chem. Gesel., **10**, 789; JB. 1877, 1029.

Landw. Vers.-Stat., **24**, 455; JB. 1879, 1108.

E. Meusel. Ber. d. chem. Gesel., **8**, 1214, 1653; Compt. rend., **81**, 533; JB. 1875, 898.

Ann. chim. phys. [5] **7**, 287; JB. 1876, 953.

Schlösing and Müntz. Compt. rend., **84**, 301; **85**, 1018; Monit. scientif. [3] **7**, 434; JB. 1877, 227, 1029.

Compt. rend., **86**, 892; JB. 1878, 1022.

Compt. rend., **89**, 891, 1074; JB. 1879, 216.

R. Warrington. Chem. News, **36**, 263; JB. 1877, 228.

Chem. Soc. J., **33**, 44; Ann. chim. phys. [5] **14**, 562; JB. 1878, 222.

Chem. Soc. J., **35**, 429; Pharm. J. Trans. [3] **9**, 985; Chem. News, **39**, 41, 224; Monit. scientif. [3] **9**, 1123; Landw. Vers.-Stat., **24**, 161; JB. 1879, 218, 1108.

F. H. Storer. Sill. Am. J. [3] **15**, 444; Chem. News, **37**, 268; JB. 1878, 222, 1022.

Downes and Blunt. Chem. News, **37**, 19; Pharm. J. Trans. [3] **8**, 512; JB. 1878, 222, 1026.

O. Hehner. Chem. News, **39**, 26, 53; JB. 1879, 221.

Gayon and Dupetit. Compt. rend., **95**, 644; Chem. Centr. [3] **13**, 804. 1882.

Dehérain and Maquenne. Compt. rend., **95**, 691, 732, 854; Chem. Centr. [3] **13**, 804. 1882.

Bull. soc. chem. **39**, 49. 1883.

The following papers bear less directly upon the influence of bacteria in the changes of nitrogenous compounds in the soil:

T. Schlösing. Compt. rend., **77**, 203, 353; JB. 1873, 1045.

E. W. Davy. Chem. News, **40**, 271; JB. 1879, 220.

Pharm. J. Trans. [3] **10**, 1; JB. 1880, 1133.

V.—AN EXTENSION OF THE THEOREM OF THE VIRIAL AND ITS APPLICATION TO THE KINETIC THEORY OF GASES.

By H. T. Eddy, C. E., Ph.D., University of Cincinnati.

[Read before the Section of Chemistry and Physics, January 18, 1883.]

1. *Introductory.*

Clausius published, in 1870, a paper upon a *New Mechanical Theorem Applicable to Heat,** which he designated as the *Theorem of the Virial,* and which he applied to the stationary *progressive* motion of the molecules of gases.

The object of this paper is to demonstrate an analogous theorem applicable to the stationary *rotary* motion of the molecules of gases, and by the aid of these two theorems to improve, to some extent, the kinetic theory of gases, especially in removing an heretofore inexplicable contradiction between the theoretic and experimental values of the ratio of the specific heats of a gas. To accomplish this most simply, it has seemed best to repeat here, in the first place, the more important parts of Clausius' original investigation, which he has supplemented by a number of important papers which have been translated and published in the *Philosophical Magazine,* between 1870 and 1876. Of these papers, the one most closely related to the original paper is one "*On Different Forms of the Virial.*"†

2. *Clausius' Theorem respecting Stationary Progressive Motion.*

A material system is said to be in stationary motion when the bodies of which it is composed do not continually depart from their initial positions, and their velocities do not continually recede from their initial values. The molecules of a gas in equilibrium are regarded as constituting such a system. For the sake of definiteness, let the system of molecules under consideration be that constituting one unit of mass of gas contained within impervious walls, although the same laws will evidently hold in case the walls are merely imaginary boundaries conceived as separating the unit of gas from other surrounding units. Let m be the mass of any molecule of this gas, and $x\,y\,z$ its rectangular co-ordinates referred to any origin; let $X\,Y\,Z$ be the components along the axes of $x\,y\,z$

*Berichte der Niederrhein. Gesellsch. für Natur u. Heilkunde, Juni, 1870.
Phil. Mag., Series [4] **40**, 122. 1870.
Pogg. Ann., **141**, 124.

†Phil. Mag., Series [4] **48**, 1. 1874.

respectively of the resultant of all the external forces acting upon the molecule m, taken as positive, when they tend to increase the co-ordinates $x\,y\,z$ respectively.

Now, by the principles of the differential calculus, we have the identical equation,

$$\tfrac{1}{2}\frac{d^2(x^2)}{dt^2}=\frac{d}{dt}\left(x\frac{dx}{dt}\right)=\left(\frac{dx}{dt}\right)^2+x\frac{d^2x}{dt^2} \quad . \quad . \quad . \quad . \qquad (1)$$

As may be seen by performing the differentiations expressed in the first two terms.

But by the fundamental equations of dynamics expressing D'Alembert's principle:

$$m\frac{d^2x}{dt^2}=X \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (2)$$

Substitute from (2) in (1), etc.

$$\therefore \quad \frac{m}{2}\left(\frac{dx}{dt}\right)^2=\frac{m}{4}\frac{d^2(x^2)}{dt^2}-\frac{x}{2}X \quad . \quad . \quad . \quad . \quad . \qquad (3)$$

The first member of (3), being one-half the product of the mass by the square of the velocity along x, expresses the energy of progressive motion of m parallel to x at any instant when its co-ordinate is x, and the force moving it in that direction is X.

In order to find the mean or average value of this energy during any interval of time t, (3) must be multiplied by dt, integrated between the limits o and t, and then the result divided by t, this being the ordinary process for finding the mean value of any function for the time t.

$$\therefore \frac{m}{2t}\int_o^t\left(\frac{dx}{dt}\right)^2dt=\frac{m}{4t}\left\{\left(\frac{d(x^2)}{dt}\right)_t-\left(\frac{d(x^2)}{dt}\right)_o\right\}-\frac{1}{2t}\int_o^t xX\,dt \quad (4)$$

The two integrals in (4) are, as just stated, expressions for the mean values of the corresponding expressions in (3): but the quantity not under the integral sign is of a different nature; it is the difference between the final and initial values (as expressed by the subscripts) of a function whose final and initial values may (if t be properly chosen) be equal, in which case the difference would vanish. But it is unnecessary so to chose t that the differences vanishes; for, by reason of the divisor t, it appears that if t be taken sufficiently large, the term under consideration vanishes, even though the final and initial values are not equal, since they can not recede indefinitely from each other. That they can not so recede appears from the identical equation, obtained in the same manner as (1):

$$\frac{d(x^2)}{dt}=2x\frac{dx}{dt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

From which it appears that the expression under consideration is dependent upon the products of quantities (co-ordinates and velocities) which, by the definition of stationary motion, can not recede indefinitely from their initial values.

Let now $x\,y\,z$ denote no longer the co-ordinates of m at any particular instant, but, instead, their mean values during the time t; and, similarly, let $X\,Y\,Z$ denote mean values, and let $x'\,y'\,z'$ be the corresponding mean velocities along the axes. Hence, we may write (4), and the two similar equations with respect to the axes of y and z, as follows:

$$m\,x'^2 = -x\,X, \qquad m\,y'^2 = -y\,Y, \qquad m\,z'^2 = -z\,Z, \quad (6)$$

in which, as just stated, the variables express mean values during the interval t, which may be taken so large as to give them sensibly constant values.

Let the unit of gas under consideration consist of n molecules, which may have equal or unequal masses; then equations like (6) apply to each of the n molecules, whose masses may be distinguished one from another by giving to m successive subscripts from 1 to n. Suppose these equations formed, and take their sum:

$$\therefore\ \tfrac{1}{2}\,\Sigma_1^n\, m\,(x'^2+y'^2+z'^2) = -\tfrac{1}{2}\,\Sigma_1^n\,(xX+yY+zZ) \quad . \quad . \quad (7)$$

The first member of (7) is the kinetic energy of the progressive motion of the members of the system, and the last member is called the *virial* of the system, and depends for its value upon the mean forces acting upon the molecules and upon their mean positions.

The theorem which has now been demonstrated, may be thus stated: the mean kinetic energy of the progressive motion of a system in stationary motion is equal to its virial.

The forces which act upon the molecules of the gas will, in general, consist of two parts: the external forces, which may be taken to be the pressure at the surface of the walls of the enclosing vessel, and the internal forces, due to intermolecular attractions or repulsions. To compute the virial of the external pressure, let the closed surface containing the unit of gas under consideration be of any shape whatever. It is evident that the pressure exerted upon the enclosed gas in equilibrium will be normal to the surface. Let p be the pressure per unit of area, and let dS be the element of area of the enclosing surface, and l the cosine of the angle which the normal to the element makes with the axis of x. Also let $X = X' + X''$, in which X' is the part of the total component force X, which is due to the pressure p, and X'' is the remainder of the component X, due to internal attractions, etc. It is to be noticed that the sign of p is opposite to that of X', because p tends to cause the molecules to

approach each other, while X' tends, when positive, to make them recede from the origin, and so from each other. Then $l\,dS = dy\,dz$.

$$\therefore\ -\tfrac{1}{2}\Sigma_1^n x X' = \tfrac{1}{2}\int x p\, l\, dS = \frac{p}{2}\int\int x\, dy\, dz \quad . \quad . \quad (8)$$

In (8) the single integration in the second member is to be extended only over the enclosing surface, for those molecules alone are acted upon by the pressure which are at the surface; but the double integration in the last member is to be extended throughout the whole volume v enclosed within the surface. In fact, the double integral in (8) expresses the total enclosed volume v occupied by the unit of gas:

$$\therefore \text{ by (8)} \quad -\tfrac{1}{2}\Sigma_1^n x X' = \tfrac{1}{2} p v \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

with similar equations for y and z, which, being added to (9), give the total virial due to the external pressure to be

$$-\tfrac{1}{2}\Sigma_1^n (x X' + y Y' + z Z') = \tfrac{3}{2} p v \quad . \quad . \quad . \quad . \quad (10)$$

In order to compute the part of the virial due to intermolecular forces, let R be the attractive force between any pair of molecules, as m_1 and m_2, and let r be the distance between them; then is $(x_1 - x_2) \div r$ the cosine of the angle which the attraction with which m_1 is drawn towards m_2 makes with the axis of x;

$$i.\ e., \quad -X_1'' = \frac{x_1 - x_2}{r} R, \text{ etc.}$$

$$\therefore\ -(x_1 X_1'' + x_2 X_2'') = x_1 \frac{x_1 - x_2}{r} R + x_2 \frac{x_2 - x_1}{r} R$$

$$\therefore\ -(x_1 X_1'' + x_2 X_2'') = \frac{(x_2 - x_1)^2}{r} R \quad . \quad . \quad . \quad (11)$$

with two similar equations with respect to the axes of y and z.

Now take the sum of the three equations similar to (11) for each different pair of molecules in the system between which intermolecular forces exist, and noticing that

$$(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2 = r^2, \text{ etc.},$$

the virial of the intermolecular forces becomes

$$-\tfrac{1}{2}\Sigma_1^n (x X'' + y Y'' + z Z'') = \tfrac{1}{2}\Sigma r R \quad . \quad . \quad . \quad (12)$$

The sum of the right-hand members of (10) and (12) is the total virial of the external pressures and intermolecular forces. Should there be other forces of sufficient magnitude to be of importance, as gravitation, electrical forces, etc., they must be also computed and added to this sum. Neglecting all these, we obtain from (7), (10) and (12),

$$\tfrac{1}{2}\Sigma_1^n m (x'^2 + y'^2 + z'^2) = \tfrac{3}{2} p v + \tfrac{1}{2}\Sigma r R \quad . \quad . \quad . \quad . \quad (13)$$

In which, among the intermolecular forces taken account of in R, may be the repulsions occurring during the encounters of molecules.

3. *A New Theorem respecting Stationary Rotary Motion.*

Let $A\ B\ C$ be the moments of inertia of any molecule of mass m, with respect to its principal axes.

Let $\frac{d\theta}{dt}, \frac{d\phi}{dt}, \frac{d\psi}{dt}$ be the angular velocities about these principal axes, then are θ, ϕ, ψ angular co-ordinates with reference to some initial lines yet to be assumed.

Let $L\ M\ N$ be the respective components about these same axes of the resultant of all the couples acting upon the molecule.

Then, by Euler's equation of rotary motion,

$$A\frac{d^2\theta}{dt^2}=(B-C)\frac{d\phi}{dt}\frac{d\psi}{dt}+L \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

with a similar equation with respect to each of the two remaining principal axes.

The following identity also holds:

$$\tfrac{1}{2}\frac{d^2(\theta^2)}{dt^2}=\frac{d}{dt}\left(\theta\frac{d\theta}{dt}\right)=\left(\frac{d\theta}{dt}\right)^2+\theta\frac{d^2\theta}{dt^2} \quad . \quad . \quad (15)$$

as appears by performing the differentiations expressed in the first two members.

Substitute from (15) in (14), etc.:

$$\therefore \tfrac{1}{2}A\left(\frac{d\theta}{dt}\right)^2=\tfrac{1}{4}\frac{d^2(\theta^2)}{dt^2}-\tfrac{1}{2}(B-C)\,\theta\frac{d\phi}{dt}\frac{d\psi}{dt}-\tfrac{1}{2}\theta L \quad . \quad (16)$$

which, with a similar equation with respect to each of the two other principal axes, is an equation of rotation applicable to any solid body, in which the first member expresses the energy of rotation about the axis considered.

In order to apply (16) to stationary rotary motion, the mean value of its various terms must be found during the interval t, as was done previously in case of stationary progressive motion.

$$\text{Let } \frac{1}{t}\int_0^t\left(\frac{d\theta}{dt}\right)^2dt=\theta'^2,$$

then θ'^2 is the mean square of the angular velocity about the first principal axis.

The integral of the second term is

$$\frac{1}{2t}\left(\frac{d(\theta^2)}{dt}\right)_t-\frac{1}{2t}\left(\frac{d(\theta^2)}{dt}\right)_0$$

in which the subscripts denote the limits to be substituted. This expression vanishes ultimately, as appears from considerations like those adduced in connection with (4) and (5).

The mean value of the product $\frac{d\phi}{dt}\frac{d\varphi}{dt}$, also vanishes, for it is evident that positive and negative angular velocities are equally frequent.

Let θ and L no longer denote particular values, but instead let them denote mean values of those quantities, and we have

$$A\,\theta'^2 = -\theta\,L, \quad B\,\phi'^2 = -\phi\,M, \quad C\,\psi'^2 = -\psi\,N \quad . \quad . \quad (17)$$

Add these equations, and the sum for n molecules is

$$\therefore\ \tfrac{1}{2}\,\Sigma_1^n\,(A\,\theta'^2 + B\,\phi'^2 + C\psi'^2) = -\tfrac{1}{2}\,\Sigma_1^n\,(\theta\,L + \phi\,M + \psi\,N)\ (18)$$

in which the first member is the total rotary energy of the system and the second member can be reduced to a form like that which has been previously obtained for the virial in case of progressive motion. For let

$$L = \rho_1\,X', \quad M = \rho_2\,Y', \quad N = \rho_3\,Z' \quad . \quad . \quad . \quad (19)$$

in which $X'\ Y'\ Z'$ are the mean component forces acting upon the molecules, with the exception of the intermolecular attractions, and $\rho_1\ \rho_2\ \rho_3$ are the arms of the mean couples $L\ M\ N$, respectively.

$$\text{Let } x = \theta\,\rho_1,\ y = \phi\,\rho_2,\ z = \psi\,\rho_3 \quad . \quad . \quad . \quad . \quad . \quad (20)$$

in which $x\ y\ z$ are mean co-ordinates, then (20) will determine the initial lines from which $\theta\ \phi\ \psi$ are measured.

By (19) and (20) we have

$$\Sigma_1^n\,(\theta\,L + \phi\,M + \psi\,N) = \Sigma_1^n\,(xP' + y.Y' + z\,Z') \quad . \quad (21)$$

$$\therefore \text{by (18)},\ \tfrac{1}{2}\,\Sigma_1^n\,(A\,\theta'^2 + B\phi'^2 + C\,\psi'^2) = -\tfrac{1}{2}\,\Sigma_1^n\,(xX' + yY' + zZ'). \quad (22)$$

It is evident that the distribution of the kinetic energy of the system of molecules, both rotary and progressive, is effected by the encounters of the molecules with each other, and with the bounding surface. The progressive motion is also directly affected by the intermolecular attractions, while the rotations can not be directly accelerated by these attractions, and this is the reason why they are not included in the forces entering the virial of rotation. When the inter-atomic attractions vanish $X = X'$, $Y = Y'$, $Z = Z'$, and in all permanent gases these equations are known to be very approximately true.

Now by (10), which included only the external pressure, and by (22),

$$\tfrac{1}{2}\,\Sigma_1^n\,(A\,\theta'^2 + B\,\phi'^2 + C\psi'^2) = \tfrac{3}{2}pv. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

Hence, by (13) and (23) we have for perfect gases

$$\tfrac{1}{2}\,\Sigma_1^n\,(A\theta'^2 + B\,\phi'^2 + C\,\psi'^2) = \tfrac{1}{2}\,\Sigma_1^n\,m\,(x'^2 + y'^2 + z'^2) \quad . \quad . \quad (24)$$

Equation (24) states that the mean progressive energy of the molecules is for perfect gases the same as their mean rotary energy. For imperfect gases, however, the energy of progressive motion differs very slightly from that of the rotary motion; a fact, the consequences of which will be more completely discussed in the latter part of this paper.

From this general statement of the equality of the mean rotary and

progressive energy of the molecules, the special cases must however be excepted in which one or more of the couples $L\ M\ N$ vanish identically. These couples may evidently all three so vanish when the molecules are in effect smooth spheres, and a single one of them may vanish in cases where the molecules may be regarded as smooth solids of revolution.

When $L = M = N = 0$,

i. e., all three couples vanish, we have by (19) $\rho_1 = \rho_2 = \rho_3 = 0$, in which case equation (20) can not be assumed to hold true. It appears, however, from (17) that in this case the energy of rotation about each axis vanishes.

In case a single couple only vanishes, let, for example, $L = 0$, then

$$\tfrac{1}{2}\Sigma_1^n(B\phi'^2 + C\psi'^2) = -\tfrac{1}{2}\Sigma_1^n(yY' + zZ') = \tfrac{1}{2}\Sigma_1^n m(y'^2 + z'^2). \quad (25)$$

in which the first member is the mean total energy of rotation, and the last is two-thirds the mean total progressive energy, as is evident from the symmetry of the axes $x\ y\ z$.

Nothing has so far been said as to the amount of the kinetic energy of atomic vibration within the molecule, a question which we shall consider subsequently, but we may here remark that there is nothing in the preceding investigation of rotary motion which would lead us to restrict its application to those molecules alone in which $A\ B\ C$ are constant, although it appears not unreasonable to suppose that the molecules of any substance are unchanged in their general character by change of state of aggregation, and that whether a substance be solid, liquid or gaseous, the molecules of which it is composed may be regarded as nearly rigid; *i. e.*, incapable of deformation to any considerable extent by finite forces, which is equivalent to supposing $A\ B\ C$ nearly invariable. We shall therefore take the terms expressing mean energy of rotation to express mean values when the moments of inertia as well as the rotary velocities are subject to fluctuations of value consistent with the state of stationary motion.

That atomic vibrations do exist may be considered to be a fact from spectroscopic evidence, for the lines in gaseous spectra can not be directly due to the very moderate progressive velocity of the molecules, but are rather to be ascribed to the intense vibrations set up within the molecules by their mutual encounters, which vibrations would rapidly be extinguished by the energy they radiate, did they not also receive radiant energy from external sources.

Should any difficulties be felt as to admitting that the mean value of the last term but one in (16) vanishes, as was done in obtaining (17), it is to be noticed that whenever two of the moments of inertia of the molecule are equal, as for example $M = N$, then (17) hold from this consideration

also, for then must the corresponding mean angular velocities be equal by symmetry, which with the equality of the two moments, M and N, is sufficient to insure the equalities expressed in (17).

The hypothesis that $M = N$ must in many cases be correct, and it may perhaps be shown in all cases not to be far from the truth, when, as stated, (17) will hold for this reason alone.

4. *Relation of the Molecular Forces to Temperature, Volume and Pressure. Expression for Work done, and the Second Law of Thermo-Dynamics.*

The first member of (13) is the mean energy of the progressive molecular motion of a unit of gas; and since heat is known to be energy, this energy is assumed to be part of the sensible heat existing in the gas,—the total sensible heat being the total kinetic energy, progressive and rotary and vibratory, existing in the gas.

Let k be the specific heat of the gas at constant volume measured in mechanical units, and let τ be the absolute temperature; *i. e.*, the zero of temperature is a state devoid of kinetic energy; then the statement just made is expressed by the equation

$$\tfrac{1}{2}\,\Sigma_1^n\, m\,(x'^2 + y'^2 + z'^2) = a\,k\,\tau \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

in which a denotes what fraction of the total heat-energy $k\,\tau$, contained in the gas, exists in it in the form of progressive molecular motion. It seems to be pretty well established by experiment that a is very nearly, if not quite, constant for permanent gases; and by permanent gases is meant any gas or vapor above the critical temperature above which it is uncondensable by pressure alone. This definition of permanent gases includes of course imperfect gases having intermolecular attractions of sensible magnitude.

From (26) and (13)

$$a\,k\,\tau = \tfrac{3}{2}\,p\,v + \tfrac{1}{2}\,\Sigma\, r\,R \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

When the last term of (27), which is dependent upon the intermolecular attractions, is so small that it can be neglected, this equation expresses the empirical law of Gay Lussac for the so-called perfect gases, and it also includes Boyle's law.

But, in order to treat permanent gases, these attractions must not be disregarded. Retaining, then, all the terms, let a variation of state of the gas occur; the relation between the variations in any change of state of the gas will be expressed by the equation

$$a\,k\,d\,\tau = \tfrac{3}{2}\,(p\,d\,v + v\,d\,p) + \tfrac{1}{2}\,\Sigma\,(R\,d\,r + r\,d\,R) \quad . \quad (28)$$

which admits of several comparisons with experimental results, which are of considerable importance in enabling us to correctly estimate the effect

of the intermolecular attractions. These comparisons will be made later in the paper.

While speaking of their attractions, it should be remarked that were it possible to actually remove all attractions between molecules which themselves occupy an appreciable fraction of the total space in which they move, the effect of their mutual encounters could be considered to be that of a feeble repulsion, for their centers can not approach within a certain small distance of each other without experiencing an insuperable repulsion; but this effect is better taken into account by regarding the volume v not as that of the total space occupied by the gas, but as the free space remaining after deducting that actually occupied by the molecules themselves. The space so occupied may be taken to be approximately that of the gas when condensed to the liquid state. Our formulæ may then be all rendered more exact by defining v to be this free space.

To obtain the work done during the expansion of a gas, divide (27) by $\frac{3}{2}v$ and multiply by dv.

$$\therefore\ p\,dv + \tfrac{1}{3}\,\Sigma\, r\, R\frac{dv}{v} = \tfrac{2}{3}\,a\,k\,\tau\frac{dv}{v} \quad . \quad . \quad . \quad (29)$$

But v varies as r^3

$$\therefore\ v = c'\,r^3, \quad \therefore\ \frac{dv}{v} = 3\frac{dr}{r} \quad . \quad . \quad . \quad . \quad . \quad (30)$$

Substitute in the second term of (29)

$$\therefore\ p\,dv + \Sigma\, R\, dr = \tfrac{2}{3}\,a\,k\,\tau\frac{dv}{v} \quad . \quad . \quad . \quad . \quad . \quad (31)$$

The first member of this important equation, which is due to Clausius,* expresses work done, the first term being that done against external forces, and the second term that done against the intermolecular attractions.

If the increment of the total work done be denoted by dw, and if, for compactness, we put $dv \div v = d\log v$, (29) becomes

$$dw = \tfrac{2}{3}\,a\,k\,\tau\,d\log v \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (32)$$

If the increment of the total energy in all forms supplied to change the volume and temperature of the gas be dh, then

$$dh = k\,d\tau + dw \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$

Now substitute the value of dw from (32).

$$\therefore\ dh = k\,d\tau + \tfrac{2}{3}\,a\,k\,\tau\,d\log v \quad . \quad . \quad . \quad . \quad . \quad (34)$$

Divide (34) by τ, etc.

$$\therefore\ \frac{dh}{\tau} = k\,d\left[\log\tau + \tfrac{2}{3}\,a\log v\right] \quad . \quad . \quad . \quad . \quad . \quad (35)$$

from which it appears that the first member of (35) is a perfect differential;

*Phil. Mag. [4] **50**, 195. 1875.

hence the second member is. But this is, as is well known, the fundamental equation of the second law of thermo-dynamics. It is to be remarked that it has been here assumed that a and k are constants, which they undoubtedly are very nearly, if not exactly, as will be shown later.

5. *Experimental Verifications and Comparisons.*

The equations (28) (31) etc., respecting the variations of temperature, volume and pressure of a permanent gas, are general, and as a particular case, we shall first consider the experiments of Thomson and Joule* in causing air and other gases to expand freely in passing through a porous plug. In these experiments the variation of temperature is very slight, and the gases obey so nearly the law of Boyle, that we are at liberty to assume in (28), $d\,(pv)=pdv+vdp=0$.

Hence (28) becomes $akd\tau=\frac{1}{2}\Sigma(R\,dr+r\,dR)$. . . (36).

In some of these experiments the gas, in passing the plug, expanded to more than four times its initial volume, so $d\,r$, the increment of the mean distance r of the molecules, must have been a considerable fraction of r. The terms in $R\,dr$ must be positive if the forces are attractive, and express the work performed in moving the molecules through the distance dr from each other against the attraction R. According to (36), if these were the only terms in the last member, or the larger ones, the temperature, *i. e.*, the kinetic energy, would be increased by passing through the plug, a result which would be in palpable contradiction to the principle of the conservation of energy; for $R\,dr$, the work done, must have been extracted from the internal energy of the gas, which would cause a decrease rather than an increase of temperature. The experiments gave a slight decrease of temperature, which shows that the terms in rdR are, in this case, negative, and numerically larger than those in Rdr.

Let us examine this point more at length. Since there was almost no variation of temperature, R may, in this case, be taken to be a function of r expressed by the equation $R=fr^{-i}$, in which f is a numerical coefficient, and i is a member for which various values (all greater than unity) have been proposed by different physicists in order to represent the actual attraction, more or less approximately, by the proposed equation.

$$\left.\begin{array}{ll} \text{If} & R=fr^{-i} \\ \text{then} & R\,dr=fr^{-i}dr \\ \text{and} & r\,dR=-ifr^{-i}d_r \\ \therefore & r\,dR=-iR\,dr \end{array}\right\} \quad . \; . \quad (37)$$

* Phil. Trans. Lond. R. Soc. 1853, 1854, 1862, or Wüllner's Experimentalphysik 3te Aufl. Bd 3. S. 463.

from which it appears that the terms in rdR are on this supposition of opposite sign from those in $R\,dr$ and i times as large; and (36) becomes

$$a\,k\,d\tau = \tfrac{1}{2} f(1-i)\Sigma\, r^{-i} dr \quad . \quad . \quad . \quad (38)$$

in which the second member is negative if $(1-i)$ is so, a result which is as already stated in agreement with experiment.

Far more decisive are the experiments of Andrews* upon the behavior of carbonic acid gas above the critical temperature. In these experiments the pressures were carried to more than 100 atmospheres at different constant temperatures, in which case (28) becomes

$$-d(pv) = \tfrac{1}{3}\,\Sigma(R\,dr + r\,dR) \quad . \quad . \quad . \quad (39)$$

By (37) this may be written

$$-d(pv) = \tfrac{1}{3} f(1-i)\,\Sigma\, r^{-i} dr \quad . \quad . \quad . \quad (40)$$

The following are the numerical results obtained at the temperature of 48°.1 C., in which p is given in atmospheres, and the volume v of the gas, at one atmosphere, is taken as 1000.:

p	v	pv
62·60	11·57	724·28
68·46	10·06	688·70
75·58	8·49	641·67
84·35	6·81	564·42
95·19	5·04	479·55
109·40	3·35	366·40

In treating this experiment as a compression, dr is negative and both members of (39) are then positive, while $r\,dR$ is shown by the numerical results to be much larger than $R\,dr$, and of opposite sign. Other results at temperatures nearer the critical temperature of 31°C., are perhaps more striking than that just quoted.

The experiments of Andrews, as well as those of Regnault and other physicists, have shown conclusively that according as the temperature of an imperfect gas is augmented, it becomes more and more nearly perfect; *i. e.*, it approaches more nearly to the state in which there are no intermolecular forces. Hence, R is also a function of τ, and such an one, that dR is negative when $d\tau$ is positive; from which it appears that in (28) the terms in $r\,dR$ are in all cases of different sign from those in $R\,dr$. In fact, if the volume remains constant, the terms in $R\,dr$ vanish, because $dr = o$ by (30).

Hence, combining this result with that previously arrived at, we see, if

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* Phil. Trans. Lond. R. Soc., 1869, p. 575, or
Wüllner's Experimentalphysik Bd.3, S. 680.

temperature and pressure be taken as the independent variables, that since $\Sigma d(rR)$ is negative for increments of each of these variables separately, it is so for both together, and hence is so always.

As another interesting example of the comparison of (28) with experimental results, let us consider Berthelot's* principle of the maximum work (*i. e.*, maximum heat) of chemical decomposition, which states that every chemical change accomplished without the intervention of energy from without, tends to the production of the body, or system of bodies, which sets free the most heat.

This is announced as a law of nature, the proof of which is to be found in a vast array of experimental evidence. It is evidently a law of fundamental importance to the theory of chemistry; and it seems to depend theoretically upon the mechanical principles involved in (28), for at the instant of chemical decomposition, the atoms must be regarded as separate bodies obeying the laws of stationary motion.

In order to introduce the condition of no exchange of energy with external bodies, let $dv=0$, $\therefore pdv=0$; *i. e.*, there is no work done against external pressure, and if vdp be small enough to be neglected, then (36) may be applied to this case. It appears, however, that the ordinary conditions of experiment from which the law was deduced, would be better represented by supposing the pressure constant;

$$i.\ e.,\ dp=0,\ \therefore\ vdp=0,$$

in which case pdv, the external work, is, as appears from experimental evidence, in general so inconsiderable as not to affect the correctness of the result, so that (36) may be considered, in this case also, to express approximately the mechanical relations involved. Considering now the case of $dv=o$, the times in (36) in Rdr are inconsiderable, since the mean distance can not be greatly changed while the total volume remains constant. But the terms in rdR depend principally upon the increase dR; *i.e.*, of the attraction between the atoms in the final chemical combination over that in the initial. If the atoms in the final arrangement obey the greater attractions, then rdR is positive. But rdR is numerically greater than Rdr; hence, by (36) heat is liberated, and the temperature is augmented. Hence, Berthelot's principle—that of several possible chemical decompositions in an isolated body, that one will occur which sets free the largest quantity of heat – follows as a direct consequence of the axiomatic truth, that the atoms will obey the more powerful attractions, which will necessarily determine the rearrangement of the atoms into molecules.

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* Essai de Mechanique Chimique, 1879, t. 2, p. 421.

As further examples of the application of our formulæ, it may be noticed that (38) can be employed to discuss the stationary motion of other systems besides that of the molecules of a gas, such as orbital and central motions, in which we have $p=0 \therefore d(pv)=0$.

Let e be the mean progressive energy of the system, then (38) becomes

$$de=\tfrac{1}{2}f(1-i)\Sigma r^{-i}dr \quad . \quad . \quad . \quad . \quad (41)$$

The only work done in changing the mean distances is

$$dw=\Sigma R dr=f\Sigma r^{-i}dr \quad . \quad . \quad (42)$$

And the total energy supplied to the system is

$$dh=de+dw=\tfrac{1}{2}f(3-1)\Sigma r^{-i}dr \quad . \quad . \quad . \quad (43)$$

From which it is seen that

$$de=\tfrac{1}{2}(1-i)dw, \qquad dh=\tfrac{1}{2}(3-i)dw \quad . \quad . \quad . \quad (44)$$

Take the case of the solar system in which $i=2$, then by (44)

$$de=-\tfrac{1}{2}dw, \qquad dh=\tfrac{1}{2}dw$$

The first of these equations states that if the mean distances of the bodies of the system are slightly augmented, then the mean kinetic energy of the system in this new state of stable motion. is less than it was before by one-half of the work expended in moving the bodies to their new positions against their mutual attractions. The second equation states that the total energy which must be supplied, is only half the work expended, the other half being derived from the decrement of the kinetic energy just mentioned.

Next take the case of an elastic system in vibration, in which $i=-1$, then by (44)

$$de=dw, \qquad dh=2\,dw.$$

These equations state the well-known fact that in this case the kinetic and potential energies are equally increased.

It is to be noticed that when $i=3$, no energy need be supplied to the system to augment the mean distances, and when i is greater than 3, energy must be supplied to decrease the mean distances,—a remarkable fact to be considered in connection with the value $i=5$, which was proposed by Maxwell.*

6. *Ratio of the Specific Heats of Permanent Gases.*

Let κk be the specific heat at constant pressure, and k that at constant volume expressed in mechanical units; then their ratio κ is the quantity in question, which has been determined experimentally for a number of gases with considerable accuracy. Its approximate theoretical value can be found as follows:

* Phil. Mag. [4] **35**, 133. 1868.

If (33) and (28) be applied to this special case in which $dp=0$, we have by definition of κk, $dh=\kappa k d\tau$; also

$$dw=p\,dv+\Sigma R\,dr \quad . \quad . \quad . \quad . \quad (45)$$

in which $p\,dv$ is the external work done, and the last term is the work done against intermolecular attractions. It will be noticed that there is no term in dw, as given, representing the work expended against interatomic forces. Were such a term needed, it would be also of the form $\Sigma R\,dr$, but its value is zero; for, suppose a molecule to consist of atoms held by elastic forces at certain mean distances, then these mean distances are not essentially changed by atomic vibrations which alternately increase and decrease those distances, *i. e.*, $dr=o$ for each molecule. The periodicity of the lines in gaseous spectra observed by Stoney and Reynolds* shows pretty conclusively that the interatomic forces are of this character.

Hence, by (28), $dw=\tfrac{2}{3}\,a k d\tau+\tfrac{1}{3}\Sigma(2\,R\,dr-r\,dR)$ . . (46)

Now, let $\Sigma R\,dr=\beta k d\tau$ . . . . (47)

in which β is an extremely small positive numerical coefficient (which is zero for perfect gases), expressing what fraction the work performed against the intermolecular attractions is of the total increment of the kinetic energy. Then, by (37), we have the following approximate value of the last term of (46),

$$\tfrac{1}{3}\Sigma(2\,R\,dr-r\,dR)=\tfrac{1}{3}(2+i)\beta k d\tau \quad . \quad . \quad . \quad (48)$$

Substitute the values just given for the various terms of (33), and divide by $k d\tau$, and we obtain

$$\kappa=1+\tfrac{2}{3}a+\tfrac{1}{3}(2+i)\beta \quad . \quad . \quad . \quad . \quad (49)$$

in which the value of a requires more extended consideration. Let b denote what fraction the increment of the mean rotary energy is of total increment $k d\tau$ of the kinetic energy, and let γ denote what fraction the vibratory energy, kinetic and potential, of the atoms within the molecule is of the same quantity.

Since these together constitute the total increment of the kinetic energy, we have

$$a+b+\gamma=1 \quad . \quad . \quad . \quad (50)$$

But in the general case, in which the molecules consist of more than two atoms, we have by (13) and (23),

$$a k d\tau=b k d\tau+\tfrac{1}{2}\Sigma d(rR) \quad . \quad . \quad . \quad (51)$$

but by (37) and (47) this becomes (after dividing by $k d\tau$)

$$a=b+\tfrac{1}{2}(1-i)\beta \quad . \quad . \quad . \quad . \quad (52)$$

* Philos. Mag. [4] **42**, 41. 1871.

Add (50) and (52)

$$\therefore\ 2a = 1 - \gamma + \tfrac{1}{2}(1 - i)\beta \quad . \quad . \quad . \quad (53)$$

Substitute this value of a in (49)

$$\therefore\ \kappa = \tfrac{4}{3} - \tfrac{1}{3}\gamma + \tfrac{1}{6}(5 + i)\beta \quad . \quad . \quad . \quad (54)$$

from which it appears, that when the vibratory energy is considerable, it will have an important influence in diminishing κ, while the intermolecular attractions may exert some slight influence to increase κ.

The experimental values of κ, as given by Meyer,* lie between 1·33 and 1·25. If we disregard the terms in β, the corresponding values of γ are 0 and $\tfrac{1}{4}$. The larger values of γ belong, in general, to the more complex molecules, and we seem here to have an experimental measure of the amount of the mean vibratory energy, kinetic and potential. If β is large in these gases, then γ is thereby increased.

In the case, however, in which the molecules consist of but two atoms each, we have by (25) the following equation instead of (52):

$$\tfrac{2}{3}a = b + \tfrac{1}{3}(1 - i)\beta \quad . \quad . \quad . \quad (55)$$

which combined with (50) and (49) gives

$$\kappa = \tfrac{7}{5} - \tfrac{2}{5}\gamma + \tfrac{1}{5}(4 + i)\beta \quad . \quad . \quad . \quad (56)$$

In this equation it is seen that β has a somewhat greater influence than it had in (54), while γ has probably a much less influence; there being but one pair of atoms to vibrate instead of three or more pairs, as in the previous case, the value of γ itself would, in general, be much smaller than before.

The most probable experimental values of κ for H_2, O_2, N_2, CO, NO, HCl, and air all lie between 1·41 and 1·39, that for air having been many times determined by the ablest experimental physicists. The mean value of κ for air, from many accordant determinations, is 1·405, while the value derived from Regnault's most accurate measurement of the velocity of sound is 1·3945, which numbers are taken from Wüllner,† who gives an extended account and comparison of these determinations.

In the case in which the molecules consist of a single atom each, we have

$$b = 0 \therefore a = 1 - \gamma \quad . \quad . \quad . \quad (57)$$

in which case (49) becomes

$$\kappa = \tfrac{5}{3} - \tfrac{2}{3}\gamma + \tfrac{1}{3}(2 + i)\beta \quad . \quad . \quad . \quad (58)$$

The vapor of mercury is perhaps the only gas regarded by chemists as consisting of molecules of a single atom each, and for this gas, Kundt

* Kinetische Theorie der Gase, 1876, S. 91.

† Experimentalphysik, 1875, Bd. 3, S. 461.

and Warburg* found $\kappa = 1{\cdot}67$. The value of κ could also have been discussed by application of Clausius' equation (34) to the case of expansion at constant pressure, and results could thus have been obtained similar to those already found.

7. *Concluding Remarks Concerning the Constitution of Gases.*

The results which have been arrived at seem to so harmonize known facts respecting gases as to lend probability to the following statements:

(1) Atoms have size and are smooth spheres; *i. e.*, are centers of force repulsive at very minute distances, and attractive at somewhat larger distances.

(2). Molecules are systems of atoms held together by the atomic attractions and repulsions in which the mean distances of the atoms are not essentially changed by temperature or pressure, and probably not by liquefaction or solidification.

(3). The mean rotary energy of the molecules is very nearly equal, in general, to their mean progressive energy; but is only two-thirds as much for diatomic molecules, and is zero for monatomic molecules.

(4). The vibratory energy of the atoms within the molecule may be a considerable fraction (as much as one fourth in the case of very complex molecules) of the total kinetic energy, and this vibratory energy should be regarded as wholly kinetic.

It has been thought improbable that the comparatively moderate progressive velocities of the molecules should originate the radiations of heat and light emitted by a gas, and hence that the atomic vibrations, which must be much more rapid, should be regarded as their mechanical cause. It has been then said that the energy of the vibratory motion set up within a molecule by an encounter must be rapidly expended in emitting radiations. Such, however, does not appear to be the fact, for in case radiations are caused by vibrations, then vibrations would apparently be caused as well by radiations from other bodies; so that a gas in equilibrium would thus receive the same amount of vibratory energy from without in the form of radiations as it loses. The vibration may, however, not be of uniform character during the interval between one molecular encounter and the next; it may take on a more regularly harmonic character as this interval elapses, and the energy of the irregular vibrations, or high harmonics, set up by the shock of the encounter may become transformed by the elastic forces into vibrations of less period, so that in a very rare gas, in which

* Pogg. Ann., **157**, 353. 1876.

the encounters are comparatively infrequent, almost no vibrations, except those of an harmonic character, may be distinguishable.

At the same time, that part of the kinetic energy of the gas which is vibratory (the relative amount of which is evidently controlled by fortuitous molecular encounters) probably suffers no change by the frequency or lack of frequency of molecular encounters, in case any small amount of dissociation present may be disregarded. These considerations go to show that the fractions a, b and γ, which have been used, are of constant value, and that k must be so also.

Watson* in his treatise has investigated the ratio of the specific heats of a gas by the aid of generalized co-ordinates, expressing the number of degrees of freedom of the system of atoms in a molecule, and, though the investigation is one of great merit, it seems to me unsuited in one particular to the system treated; for it presupposes, as I understand it, rigid connections between the members of the system. Since an elastic connection is neither a degree of perfect freedom, nor of perfect constraint, but something intermediate, there is no whole number of degrees of freedom in the system. If molecules were rigid bodies, such systems would possess in general six degrees of freedom, and thus would have six generalized co-ordinates, which might be taken as three rectangular and three angular co-ordinates, such as have been employed in this paper. When, however, the molecules are smooth solids of revolution, the number of co-ordinates would be reduced to five, and, in case of smooth spheres, to three.

Now, if these are degrees of perfect freedom, it seems demonstrable that the kinetic energy which is distributed among them by fortuitous encounters would be equally shared by them; *i. e.*, the energy with respect to each co-ordinate would be of the same amount, a result which agrees with what has already been proved for perfect gases. But in case partial constraints, not amounting to the loss of entire degrees of freedom, are introduced with respect to any of the co-ordinates, the energy will no longer be equally distributed among all the co-ordinates, but will be influenced by these constraints. This is what was found to take place in imperfect gases, where the intermolecular attractions affect the components of the progressive motion, but not the rotary components.

In many points the results arrived at in this paper are in substantial accordance with those found by Boltzmann† in his important papers upon this subject; but both he and Watson regard some of the experimental

* Kinetic Theory of Gases, 1876, p. 38.

† Sitzungsb. d. Wien. Akad., Bd. 63, 66, 74.

values of κ, and in particular all values less than 1·33, to be in contradiction to theory. So far as is known to the author, the investigation which he has here given to the question explains for the first time this contradiction which Watson (p. 39) regards as "the great difficulty in the establishment of the kinetic theory of gases on the molecular hypothesis."

CINCINNATI, *January* 18, 1883.

NOTES.

THE WATERPHONE.

BY THOS. J. BELL.

[A paper on the Wastage of Water, by Mr. Bell, was presented before the Section of Mechanics and Engineering, January 23, 1883, and was intended for this number; but its publication is unavoidably deferred.—EDS.]

THIS instrument is used for the detection and location of flows of water in underground conduits, and is more especially adapted for the correction of waste of water due to leakage or improper use.

The principle embodies the conversion of the vibrations induced in the conduit by the flow of water through or from the same, and the amplification of the sound waves by means of a diaphragm whose nodal sounds are transmitted to the ear.

The device consists of a diaphragm, attached to a metal rod, inclosed in a telephone trumpet. A thread is cut on the end of the rod for connection to the customary hydrant key, used for operating the stop of the service branch supplying water to the premises.

Inspections are made after midnight, when, it is presumed, water is not used legitimately. The inspector places his key on the stop, and then attaches his waterphone. If running water occurs, however small, the sound occasioned thereby is readily heard by the inspector, who notes the location and visits the premises the next day for the cause. Nearly twenty-five per cent. of the cases inspected in Cincinnati showed wastes of some nature, and the results have already been beneficial to the water supply. Particulars of this invention are more fully described in *Engineering News*, Vol. 9, No. 25, and *Sanitary Engineer*, Vol. 6, No. 2 and 5.

DISCOVERY OF A METHOD FOR IRIDIUM PLATING.

BY WM. L. DUDLEY.

[Read before the Section of Chemistry and Physics, March 1, 1883.]

THE problem of electroplating with iridium has been solved, by employing a suitable solution of the metal and properly regulating the electric current. The solution is kept at uniform strength by using a plate

of iridium as the anode. The metal is deposited in the reguline state, and takes a good polish. A buffing wheel that will grind off nickel plating in a few moments, only serves to polish the iridium. Thin platinum foil, coated with iridium, retains its flexibility; and if the coating is not too thick, it will not readily scale off. Copper plates for engravings, faced with iridium, would possess marked advantages over steel engravings.

Details of this process will be announced in due time.

Studies in Chemical Dynamics.

[The following abstract is from a paper by Prof. W. Ostwald of Riga, in Jour. prak. Chem. [2] **27**, 1–39 (1883). Read before the Section of Chemistry and Physics, by Robt. B. Warder, March 1, 1883.]

An ordinary mechanical force may be measured either statically, by the value of the force required to hold it in equilibrium, or dynamically, by the speed imparted to a given mass in a given time; so also the relative intensity of chemical affinity may be compared by observing the conditions of equilibrium or the speed of chemical reactions. The former method having been used in the author's volume-chemical studies,* the latter is the subject of his present paper.

For each experiment, 1 cc. of a 2-normal solution of pure acetamide, mixed with 2 cc. of normal acid, was kept for a measured interval of time (2 minutes to 50 days) at 65° C. or at 100° C.; variations of temperature, in experiments that lasted for weeks, were kept within less than 0·05° C. After cooling, the ammonium salt present was decomposed by sodic hypobromite, and the volume of free nitrogen was measured in a modified form of Winkler's azotometer. The object was to determine the speed of the reaction, under similar conditions, in the presence of various acids.

In the primary reaction, the amide and water alone are concerned,

$$CH_3.CO.NH_2+H_2O=CH_3.COO.NH_4;$$

yet the presence of the acid, as a "predisposing" agent is essential. Regarding the amide and the acid as the only varying active bodies present, equivalent amounts of both being neutralized as the action proceeds, we should have (according to Guldberg and Waage's law)

$$\frac{dy}{dt}=c\,(a-y)^2, \text{ or}$$

$$\frac{y}{a-y}=act,$$

where a and $a-y$ respectively represent the quantities of acetamide present at the beginning and the end of the interval t, and c is a constant. The several series of observations, expressed graphically, correspond approximately with the theoretical curve. With chlorhydric, nitric, and bromhydric acids, the reaction, per unit of the active bodies, seems to be somewhat accelerated by the neutral salt formed. The curve for

*Jour. prak. Chem. [2] **18**, 262 (1878).

trichloracetic acid agrees with theory. With other monobasic acids, the reaction is gradually retarded; perhaps by a secondary reaction between the acid and the ammonium salt, perhaps by an incipient formation of the corresponding amide,—or perhaps the fundamental hypothesis must be modified. With the dibasic and tribasic acids, especially with the latter, the reaction is greatly retarded by the formation of acid salts. This is more marked at 100° than at 65°.

The general results, based upon the means of many series of determinations, are included in the following table: The "time required for one-half the complete reaction," expressed in minutes, was determined by interpolation. The relative intensity of chemical affinity, as expressed in columns *a* and *b*, is deduced from the mean co-efficient of speed for the first half of the reaction, upon the hypothesis that the speed varies as the square of the chemical force, as discussed by the author in Jour. prak. Chem. [2] **16**, 422 (1877). Column *a* denotes the relative affinity between the several acids indicated and ammonia, at 65° C.; column *b*, at 100° C.; and column *c* contains the results already published, as determined statically from the volume of solutions at 20° C.

Acid used.	Time required for one-half the complete reaction.			Relative intensity of chemical affinity.		
	At 65°C.	At 100°C.	Ratio.	*a*	*b*	*c*
HCl	72·1	4·98	14·48	100	100	98
HNO_3	75·2	5·35	14·06	98	97	100
HBr	74·0	5·14	14·39	98	98	95
$CCl_3 \cdot COOH$	112·8	....	......	80	....	80
$CHCl_2 \cdot COOH$	433·7	....	....	40·8	....	33
$CH_2Cl \cdot COOH$	4570	....	....	13·0	....	7·0
$H \cdot COOH$	28950	2138	13·55	5·16	4·83	3·9
$C_2H_4OH \cdot COOH$	29340	2128	13·80	5·13	4·85	3·3
$CH_3 \cdot COOH$	....	....	......	....	2·34	1·23
$SO_2(OH)_2$	180·0	14·10	12·77	65·4	59·4	66·7
$(COOH)_2$	1516	118·6	12·80	22·6	20·5	....
$C_2H_2(OH)_2(COOH)_2$	13660	929	14·71	7·51	7·32	5·2
$C_2H_3OH(COOH)_2$	35310	....	....	4·67	....	2·82
$C_2H_4(COOH)_2$	....	7976	....	2·55	2·50	1·45
$C_3H_4OH(COOH)_3$	44810	3088	14·53	4·01	4·01	....
$PO(OH)_3$	....	3880	....	....	3·58	....
$AsO(OH)_3$	....	4005	....	....	3·53	....

Ostwald has exhibited great ingenuity, both in the general plan of the research, and in overcoming the several experimental difficulties so as to ensure accuracy. The general accordance of his results, as obtained by statical and dynamical methods, is hardly more striking than the variety of questions suggested for future experimental and mathematical investigation.

Flow of Liquids on the Surface of a Burette.

BY ROBT. B. WARDER.

[Read before the Section of Chemistry and Physics, February 23, 1882.]

In the course of experiments upon the speed of saponification, it became necessary to make a careful study of the various sources of error. A 60 cc. burette, which was filled with a solution of sodium hydrate (5 grams to the liter), was discharged as quickly as possible, and readings were then taken at intervals of one-half minute, as the liquid adhering to the sides of the tube slowly moved down to the meniscus. It might be imagined that the meniscus would rise most rapidly immediately after the pinch cock was closed, and continue rising more and more slowly until it became constant. This is not the case, however, for the most rapid change was at the end of about two minutes; while full ten minutes must be allowed to pass, in order to obtain constant readings. One series of readings, given below, was amply confirmed by several similar series.

Times are stated in minutes, from the moment the pinch-cock was opened. Twenty-three seconds were required for the discharge.

Time.	Readings.	Rise in cc. per minute.	Time.	Readings.	Rise in cc. per minute.
0·5	59·41 cc		5	59·25	·02
1	·40	·02	5·5	·24	·02
1·5	·38	·04	6	·23	·02
2	·35	·06	6·5	·22	·02
2·5	·32	·06	7	·21	·02
3	·30	·04	8	·20	·01
3·5	·29	·02	9	·19	·01
4	·28	·02	11	·18	·005
4·5	·26	·04	15	·18	·000

Now why did the top of the liquid column rise but ·01 cc. during the first half-minute, ·02 during the second, and ·03 during the third? We may suppose that as liquid is discharged and the meniscus falls, a film of some definite thickness is left upon each portion of the wall. But the thickness of the film does not remain uniform. The moment the pinch-cock is closed, the wall immediately above the meniscus has a film of the average thickness; but the solution has now been draining away from the upper part of the tube for one-third of a minute, and accumulating below; so that the maximum thickness of the film will be towards the middle of the burette. The actual speed of the flow will also be greatest in this portion, and thus the gradually increasing rate at which the meniscus rises is fully accounted for.

It is evident that the more viscous the liquid, the greater the quantity left for a time upon the glass. Chemists should of course be careful to

allow sufficient time, in volumetric analysis, before reading the burette; for a one-eighth normal solution of sodium hydrate is not remarkably viscous, and yet the meniscus continued to rise for ten minutes, after a discharge of about 60 cc.

SUGGESTIONS FOR THE SCHOOL OF TECHNOLOGY.

BY ROBT. B. WARDER.

[Read before the Section of Mechanics and Engineering, November 28, 1882.]

AN interest has lately been manifested in the proposed increase of facilities for technical education. In planning a technical school, at least four distinct elements must be considered; namely, the educational facilities already provided, the age and preparation of the pupils to be admitted, the objects to be sought, and the means at command for the proposed school. Instruction must always be adapted to the capacity of the pupil; yet the importance of the mental discipline enjoyed, as preparatory to a course of technical instruction, has often been most unfortunately overlooked.*

The history of the evening classes shows that they have been exceedingly useful; the Institute should extend all possible facilities to the artisans of Cincinnati, by offering technical instruction in the evenings. Day classes also may prove of great value to those who will become artisans or foremen a few years hence. Statistics must furnish the data for quantitative discussion of social problems. The following table of attendance in the public schools of Cincinnati has been taken from official sources, for the year 1880–81. See next page.

This table shows that the greatest percentage of loss (except at the entrance to the University) occurs in the C and D grades of the High Schools, at the age of about sixteen years. We may estimate that at least five hundred pupils drop out from the course annually between the Intermediate and the High Schools, and three hundred more within the next year. Having "a good common school education," many of these lose interest in their studies, or feel compelled to seek employment for self-support. The Ohio Mechanics' Institute, without neglecting the present evening classes, may appropriately extend some special inducement to encourage these to continue their education two or three years longer. The courses provided for these grades should still be strictly educational, including a fair proportion of general information; but about one-third of the time may be given to drawing, mensuration, natural philosophy, and elementary principles of construction. Shop practice for working in wood and iron should be included, as soon as the needful funds are provided; but even

*I have elsewhere (Jour. of the Amer. Agr. Assoc., 1, No. 3 and 4, p. 68) called attention to a remarkable instance of such oversight, the Industrial University of Illinois being placed on the same level with the Polytechnic School at Munich, notwithstanding at least four years difference in the preliminary training required. See Report of an International Conference on Education (held at Philadelphia, in 1876), published by the U. S. Bureau of Education.

	Grade.	Average age of pupils when entered.	Number of pupils enrolled.	Difference in successive years.	Percentage of loss.
District Schools.	H	6.7	8936		
	G	8.0	5490	3446	39
	F	9.2	5066	424	8
	E	10.3	4198	868	17
	D	11 2	3479	719	17
Intermediate Schools.	C	12.2	2537	942	27
	B	13.0	1661	876	35
	A	14.0	1118	543	33
High Schools.	D	15.2	612	506	45
	C	16.1	295	317	52
	B	16.9	174	121	41
	A	17.5	108	66	38
Candidates for University Degrees.	1st Year,		22	86	80
	2d Year,		16	6	28
	3d Year,		9	7	44
	4th Year,		8	1	11
	Post-Graduates,		8		

with the present income, supplemented by moderate tuition fees, a great deal could be done by the joint action of the Ohio Mechanics' Institute and the Union Board of High Schools. Under the present regulations, the High School pupils are required to attend about seventeen recitations each week. Afternoon classes could be organized at the Institute, for industrial drawing and other special branches, if provision should be made to allow members of these classes to pursue a partial course in the public High Schools.

The following scheme of studies, if not the best, will at least illustrate a plan by which a real gain may be secured, with small outlay, in the general information and the technical training of our manufacturing population. The studies of the first group are already provided in the High Schools, with the number of weekly exercises expressed below.

	Grade D.	Exercises per week.	Grade C.	Exercises per week.
High School Studies.	Algebra,	4	Algebra (1st term),	4
	History,	3	Geometry (2d term),	5
	Physiology (1st term),	2	Natural History (1st term),	3
	Composition and Elocution,	2	Rhetoric (2d term),	2
			Composition and Elocution,	2
Special Studies.	Drawing,	3	Drawing,	3
	Natural Philosophy,	3	Mechanics,	3
	Elements of Geometry and Trigonometry (2d term),	2	Special Problems,	2

VOL. II. JUNE, 1883. NO. 2.

SCIENTIFIC PROCEEDINGS

OF THE

Ohio Mechanics' Institute.

PUBLISHING COMMITTEE.

ROBT. B. WARDER, *Editor.*

LEWIS M. HOSEA. JAS. B. STANWOOD.

OHIO MECHANICS' INSTITUTE,
DEPARTMENT OF SCIENCE AND ARTS.
CINCINNATI, OHIO.

Entered at the Post Office, at Cincinnati, O., as Second-Class Matter.

See Special Notice on Last Page of Cover.

CONTENTS.

The Publishing Committee have been gratified by receiving an unusual number of papers from the Section of Mechanics and Engineering. Members desiring extra copies of this issue for distribution, may request them at the office.

Several "Mechanical Notes" by Harry M. Lane, M. E. (illustrated), are ready for the September number. The remaining parts of Professor Eddy's paper on "Developments in the Kinetic Theory," will probably be published at the same time.

Contributors are responsible for any statements in their papers.

Reprints of articles accepted for publication will be furnished to authors at cost, if due notice is given.

Contributors of all papers are requested to place their manuscripts or abstracts in the hands of the Publishing Committee as promptly as possible.

SCIENTIFIC PROCEEDINGS

OF THE

OHIO MECHANICS' INSTITUTE.

VOL. II. JUNE, 1883. NO. 2.

PROCEEDINGS OF THE DEPARTMENT OF SCIENCE AND ARTS.

Meeting of April 12.

REPORTS were received from the Section of Chemistry and Physics, and from that of Mechanics and Engineering.

Professor F. W. Clarke gave a lecture on "THE FOURTH STATE OF MATTER," illustrated by a set of Crookes tubes; he also suggested the probability of a fifth state, or ultra-solid matter, if it should ever be found possible so to compress a body as to allow the molecules and atoms no space for motion.

PROCEEDINGS OF THE SECTION OF MECHANICS AND ENGINEERING.

Meeting of February 27.

MR. J. D. DANKS read a paper on "MECHANICAL PUDDLING."

The annual election resulted as follows: Chairman, Harry M. Lane; Vice-Chairman, J. G. Danks; Secretary and Member of Publishing Committee, Jas. B. Stanwood; Member of Lecture Committee, C. B. McMeekin.

Meeting of March 27.

Harry M. Lane, M. E., read a series of "MECHANICAL NOTES," including the following: "The Manufacture of Sporting Gun Barrels," "Friction of Slide-Valves," "Slide-Valve as a Water Relief Valve," "Compression and Cushion," and "Manufacture of Swiss Toys."

Meeting of April 24.

Mr. Alfred R. Payne read a paper on "UTILIZATION OF SEWAGE FROM HILLS."

PROCEEDINGS OF THE SECTION OF CHEMISTRY AND PHYSICS.

Meeting of March 1.

PAPERS were presented as follows: "DISCOVERY OF A METHOD FOR IRIDIUM PLATING," by Professor Wm. L. Dudley (see page 43); "STUDIES IN CHEMICAL DYNAMICS" (abstract from Professor W. Ostwald, see page 44); and "PHOSPHIDES OF PLATINUM" and "A CHEMICAL THEORY OF ODORS," by Professor F. W. Clarke.

Mr. O. T. Joslin (as stated in Professor Clarke's first paper) had found that platinum fused with phosphorus* gained weight in the ratio required for Pt_3P_5; this result was confirmed by analysis. Aqua regia separated the fused mass into a soluble portion, agreeing with the formula $Pt\,P_2$, and an insoluble portion, Pt P. By long roasting, these phosphides are reduced to Pt_2P.

Meeting of April 26.

A paper on "TARTRATES OF ANTIMONY" was presented by Professor F. W. Clarke; a preliminary note upon certain "DEVELOPMENTS OF THE KINETIC THEORY OF SOLIDS, FLUIDS, AND GASES," by Professor H.T. Eddy; and suggestions for "PROPOSED COMPUTATIONS OF THE SPEED OF CHEMICAL REACTIONS," by Professor Robert B. Warder.

Many published experiments relating to the speed of chemical reactions still await discussion. Professor Ostwald† has given us an admirable illustration of dynamical investigation, as applied to the quantitative study of chemical affinity; while some experimenters have made no attempt to apply any theory to their reactions, or to deduce the coefficients of speed. The day, hour, and minute are all in use as units of time. A comparison of all trustworthy data, with reduction to some uniform system of units, would make it easier to compare the results of many chemists with each other, and with the thermal, electrical, or contraction phenomena of the same reactions. Besides the absolute determinations of speed by the dynamical method, relative determinations may be deduced from the conditions of equilibrium in reciprocal reactions. The task of computation now proposed is somewhat tedious; but the labor may be lessened by adopting a systematic course. If members of the Section will undertake this work, the results may be of value to students in the field of physical chemistry. It should not be our purpose to interfere with investigations now in progress, where the author may have published experimental data with the intention of offering future mathematical discussion himself; but rather to discuss those investigations that seem to have been ended, with such recent results as may be placed at our disposal for this purpose. An index to the literature of speed of reactions, on the plan

*Compare Holland's process of fusing iridium, in these PROCEEDINGS, **1**, 35–40.

† See abstract in these PROCEEDINGS, **2**, 44.

suggested by the American Association for the Advancement of Science in 1882, may be included by the Section as part of their work.

The following resolutions were adopted, and Professor Robt. B. Warder was requested to take the general direction of the work proposed:

Resolved, That this Section undertake the computation of numerical values for the speed of chemical reactions upon some fixed system of units.

Resolved, That the co-operation of other chemists and physicists be invited, either in communicating such experimental results as they may be willing to place at the disposal of this Section, in suggesting the most convenient units and formulas, in comparing the results from other departments of physical chemistry, or in such other work as may be helpful.

Resolved, That reports of progress be published, from time to time, with our Scientific Proceedings.

VI.—THE WASTAGE OF WATER.

By Thos J. Bell.

[Read before the Section of Mechanics and Engineering, January 23, 1883.]

Air, sunshine, and water are Nature's free and bounteous gifts to her children; and so long as man remains in a state of nature, these three elements, so essential to his health and happiness, may, as a rule, be enjoyed without stint or restriction. But as men come under the influence of civilization and adopt fixed places of abode and engage in permanent occupations, they soon begin to congregate together into communities and to levy a heavy tax upon Dame Nature's resources, and thwart and interfere with her generous provisions. Thus we see the air, in thickly settled districts, rendered impure by dust and noxious vapors and gases; the sunshine shut out by encroaching and overshadowing buildings and clouds of black smoke from thousands of chimneys; and the water contaminated in a great variety of ways, and, especially in cities, the demand increased far beyond the local supply.

Man, by his centuries of wild life amid the unrestricted bounties of Nature, has come to have a sort of innate and instinctive feeling that he is entitled to the unlimited enjoyment of these three free gifts; and, hence, he never takes readily or kindly to their arbitrary or necessary curtailment. Of the masses of people residing in cities, but a small proportion have any kind of an adequate idea of the cost of a good supply of good water to the community. Those persons whose duty it is to provide a sufficient supply for public use, and those other comparatively few people whose interest or inclination leads them to inform themselves upon this question, constitute but a small percentage of the population.

On this account, it happens that most consumers of water are very thoughtless and improvident in its use. They have no realization of

the enormous expense attending its impounding, storage, and mechanical delivery and distribution through intricate channels to distant points. The supply of water to the consumer requires the highest engineering skill and vast outlays in the construction of the necessary machinery, apparatus, and appliances. Sanitarians tell us that no article is more difficult to procure than an adequate supply of pure, wholesome water.

Consumers of water in Cincinnati have never learned its great value. The supply here is too lavish and abundant. In Great Britain, on the contrary, water is furnished in limited quantities only. In the great metropolis of London it is supplied for only a few hours daily, during which time consumers must store in their cisterns, or elsewhere, what they will need for the whole day.

Water consumers fail to realize that they endanger the water supply and jeopardize property as much by wasteful habits in the use of water as they would by direct interference with the work of the fire department. Let us see how easy it is to cripple our water supply. The middle service of the city is supplied from Eden Park Reservoir through two 36-inch (91 cm.) mains and one 10-inch (25 cm.) main. The lower service is supplied from the old reservoir on Third Street, through two 20-inch (51 cm.) mains. On these mains there are 24,500 house service or branch connections and 380 hydraulic elevators.

The cross-sections of the feeding mains give a total of 2,630 square inches (16,968 cm^2.); those of the service branches, 11,600 square inches (74,843 cm^2.); and those of the hydraulic elevators, 2,700 square inches (17,420 cm^2.). It is seen that the cross-sections of the feeding mains lack fully eighty-two per cent. of being equal to the cross sections of the service branches and the elevators. The cross-sections of the elevator pipes alone are greater than those of the feeding mains. These facts render it impossible, during the day, when water is most in use, to maintain the static or reservoir pressure; while at night, when but little water is used, the return to the static head causes impact, or water-ram, from the accumulation of compressed air, which finally results in the bursting of pipes or the springing of leaks at joints.

These two service branches supply, approximately, 100,000 hydrants and faucets of various sorts, and about 10,000 water-closets. A faucet with a small leak producing a drip will waste from ten to fifty gallons per day, while a closet, if left running continuously, will waste 15,000 gallons in twenty-four hours. A faucet leak is rarely corrected until it is wasting water at the rate of from 200 to 1,000 gallons per day. Thus it is seen that twenty-five per cent. of our water-closets can run away more water

than the combined capacity of our present pumps, while twenty per cent. of our faucet-stops may waste more water than the average consumption for 1881.

Of course, officials do all in their power to guard against emergencies and to protect the interests of the city and of consumers. But warnings through annual reports have but little effect upon that large body of consumers who, through carelessness or negligence, waste so much water. If at any time the water supply should fail—and many a time it requires the most diligent and overtaxing effort on the part of those in charge to prevent its failing—the poor official must be sacrificed, when the fault lies solely in the extravagant and careless habits of water consumers.

Citizens continually complain of the high water tariff, and, as a rule, attribute it to official incompetence and dishonesty. But it is hardly possible that any mismanagement of those having charge of the water supply could compare in evil results with the wasteful habits of consumers. In addition to the exorbitant charges for water-rents, the following consequences of an extraordinary consumption of water should be noted:

1. If the consumption of water increases beyond reasonable and anticipated bounds, new pumping engines, reservoirs, mains, and other improvements are constantly made necessary. It becomes impossible to estimate how long the reserve resources will last. The Cincinnati pumping works are often so taxed as to render sudden demands upon the reserve supply necessary. On this account, a water supply is sometimes greatly jeopardized before new engines can be built. The city of Pittsburgh, recently, in such a dilemma, was forced to appeal to private interests to aid in keeping up a sufficient supply.

2. The habit of waste has grown to such an extent that engineers, in designing a water supply, are compelled to double the per capita rate of consumption which was found amply sufficient forty years ago. But notwithstanding this, new water works, after a few years' use, are found inadequate in their capacity. Thus, the city of St. Louis constructed an entirely new system of supply which was put into operation in 1872. This provided for a per capita consumption of forty-four gallons (167 l.) per day. Already, after the lapse of but ten years, it is found that the average consumption per capita has increased to seventy-five gallons (284 l.), a quantity far exceeding the safe capacity of the works.

3. The waste destroys the static or reservoir pressure; prevents the flow on upper stories, thus robbing some consumers; requires large mains; and causes the accumulation of air in the pipes and an impact of water, resulting in joint leaks and burst pipes.

4. Where there is large waste, it becomes impossible to filter the required amount of water. The city of London filters two-thirds of the water supply, using 92 acres (37·23 hectares) of ground for basins for this purpose. To do this is possible in London, only from the fact that the consumption is strictly for legitimate uses. The daily rate is now the same that it was in 1849, viz: 33 imperial gallons (40 U. S. gallons or 150 l.) for each inhabitant.

Below is a table showing the increase of the per capita consumption in five American cities, as a direct result of the wasteful habits of consumers:

TABLE I.

Boston..........	per capita rate in	1850,	30 gallons;	in 1881,	92	gallons.
Brooklyn.......	" "	1866,	17 "	" 1880,	54	"
Chicago.........	" "	1867,	43 "	" 1880,	114	"
New York.....	" "	1867,	62 "	" 1876,	100	"
Philadelphia..	" "	1867,	56 "	" 1880,	67	"

In New York, in 1876, the maximum capacity of the Croton Aqueduct was reached, viz: 96,000,000 gallons daily, and the city has since been limited to that amount. The pressure is so reduced that water does not flow in upper stories even at night, and in some localities it barely runs in the basement during the day. Consumers have been compelled, at great expense, to provide pumps upon their premises to force a supply of water into the various stories of their buildings. Owing to the increase of population –the water supply remaining the same meanwhile—the consumption, per capita, has decreased from 100 gallons in 1876 to 65 gallons in 1880. The city is now asking the Legislature for permission to borrow $14,000,000 for the construction of an additional aqueduct and dam. A bill to this effect was passed by the Legislature, but was vetoed by Governor Cornell, who assigned as one of his reasons for so doing, the fact that if the waste were stopped the present aqueduct would be sufficient for many years to come.

Wastage has increased the per capita consumption of water, in Cincinnati, from 21 gallons (79 l.) in 1845 to 87 gallons (329 l.) in 1881. The demand has been doubled each decade. Mr. Americus Warden, while Engineer of the Pumping Department, in 1875, made some careful observations regarding the quantity of water wasted. He found the loss to be over 1,250,000 gallons between the hours of twelve, midnight, and four A. M.; or, at the rate of 283,000 gallons per hour, equal to nearly 7,000,000 gallons in twenty-four hours.* Now if we take into

* See Report Cincinnati Water Works, 1875, page 70.

consideration the general carelessness and indifference of consumers in the use of water during the day, and estimate the loss in this way and add it to the above, we find a total loss of about fifty per cent. of the whole amount pumped into the reservoirs. The engineers in Chicago and St. Louis estimate the loss from waste in those cities at fifty per cent. Mr. Warden placed the financial loss, in full, for pumping this wasted water at $29,000 per annum. That was in 1875. The actual expenses to the city from abuses in water privileges were estimated, in 1881, at one-half the regular running expenses of the pumping service; that is, $115 daily, or $41,975 per annum.

But this loss is insignificant compared with the constant demands upon the public purse for funds for the construction of new machinery. Mr. A. G. Moore, Superintendent of the Cincinnati Water Works, in his Annual Report for 1880, page 27, says: "The annual loss to the works by abuse in the water privileges, if reduced to a revenue, would be startling. But far more important than this is the dangerous condition the pumping works are placed in by overtaxing the pumps, and the necessity of constantly providing additional engines to meet the necessary demands for water." This is a contingency that can not be reliably anticipated; for the abuse of water, unless restricted, is an uncertain element.

Since 1863, the city of Cincinnati has expended over three million dollars in betterments for her Water Works. This was made necessary almost wholly by this wastage of water. But notwithstanding this great expenditure, the situation is no better to-day than it was then, and there is even less security against fire. The consumption of water at that time, twenty years ago, viz: 6,000,000 gallons daily, was about what it should be to-day with our present population, if the per capita rate in the cities of Great Britain be taken as a standard. The following table shows the rate of consumption in five of these cities:

TABLE II.

	Population.	Daily Consumption.	Per Capita Consumption.
Sheffield	300,000	6,500,000 U. S. gallons.	21·6 gallons.
Manchester	900,000	21,600,000 " "	24·0 "
Liverpool	700,000	19,000,000 " "	27·0 "
Birmingham	500,000	14,000,000 " "	28·0 "
London	4,000,000	156,000,000 " "	39·0 "

If the consumers of the latter city had not grown accustomed to the exercise of great vigilance and prudence in the economical use of water,

the demand would be nearly 1,000,000,000 gallons daily—a quantity hardly obtainable from all the rivers, wells, and springs within any reasonable distance of London. The summer flow of the Thames does not exceed 300,000,000 gallons daily at the pumping stations.

The following table furnishes matter for some interesting comparisons:

TABLE III.

Per capita consumption of water in American and foreign cities.

American Cities.	Date	U. S. Gallons.	Liters.	Foreign Cities.†	Imp. Gallons.	U. S. Gallons.	Liters.
Washington	1880	176·0	666·3	Glasgow. .	50·0	60·0	227·1
Detroit	1881	154·0	583·0	Plymouth...	49·0	58·8	222·6
Jersey City............	1880	122·0	461·9	Aberdeen...	45·0	54·0	240·0
Buffalo	1881	106·0	401·3	Edinburgh.	40·0	48·0	181·7
Milwaukee............	1880	106·0	401·3	Dublin	38·0	45·6	172·6
Pittsburgh.............	1880	102·0	386·1	London......	32·5	39·0	147·6
Boston	1881	92·0	348·3	Bolton.......	25·0	30·0	113·6
Cincinnati..............	1881	87·0	329·4	Leeds........	23·25	27·9	105·6
New York.............	1880	80·0	302·9	Liverpool...	22·5	27·0	102·2
St. Louis................	1880	71·0	268·8	Birmingh'm	22·5	27·0	102·2
Philadelphia...........	1881	70·0	265·0	Manchester	20·0	24·0	90·9
San Francisco.........	1880	70·0	265·0	Sheffield	18·0	21·6	81·8
Louisville......	1881	70·0	265·0	Norwich....	16·0	19·2	72·7
Cincinnati*.............	1882	69·7	263·8				
Cleveland............ ..	1880	64·0	242·3				
Brooklyn................	1881	58·0	219·6				
Providence (meters)..	1880	31·0	117·4				

This table shows clearly the tendency of consumers on this side of the ocean to the extravagant use, or rather waste, of water. The great difference in the amounts of water used in the two countries may be attributed almost entirely to the good effects of the following general rules in force in the cities of Great Britain:

1. A diligent and business-like attention is given to the water supply, and there is a prompt and hearty encouragement of all improvements which will prevent waste.

2. Methods of limited and intermittent supply are adopted.

3. Stringent laws governing water privileges and connections are in force, backed by parliamentary power.

4. Plumbers are required to take out licenses, and their work is carefully inspected and tested.

* After introduction of the Bell Waterphone.

† From "Water: Its Composition, Collection, and Distribution," by Joseph Parry, C. E., pages 89, 90.

5. Officers are selected for their special qualifications, and retained for efficiency, integrity, and attention to their work.

6. There is a constant inspection of water fittings from house to house.

7. There is a guarded method of supply, including official approval of plumbing devices so as to avoid the constant flow of water, especially in closets.

In reference to this last rule, it may be stated that no closet is allowed to be fitted directly from the service-pipe. The water must be drawn from a cistern, so regulated that but one and a half or two gallons (six to eight l.) can be used at each flush. Indeed, all house supplies are drawn through cisterns. These cisterns are each supplied with an overflow pipe which is conducted to the outside of the premises, so that a police officer or inspector may at once detect any waste. These cisterns, water-closets, cocks, and other appliances must not only be of approved patterns, but must each be stamped by regular water officials appointed for that purpose.

The marked disparity noted in the per capita consumption of water in cities of this country and of Great Britain, gives rise to the question as to what should be considered a proper quantity of water for a given population to use. May it not be that, instead of the use of water being too lavish on this side, our English friends are afraid of it and too beggarly in its supply and use?

Humber, in his valuable work, "A Comprehensive Treatise on the Water Supply of Cities and Towns," has given this subject careful attention. He finds that the amount of water per capita actually needed varies in different places according to circumstances. Thus he finds that in some cities, as Norwich, 17 or 18 gallons per inhabitant each twenty-four hours, are sufficient; while in other cities, as in Glasgow, it may reach 54·5 gallons. These quantities include water for domestic and manufacturing purposes, street watering, flushing sewers, and the extinction of fires. Mr. Humber states that 12 gallons are sufficient for washing, drinking, and bathing purposes, and water-closets. The same eminent authority further states that investigations were made in London, showing that in houses of the first class, of from twelve to twenty rooms and with every convenience, the consumption was 15·44 gallons per head; in second class houses, having water-closets, the consumption was 8·89 gallons; in houses of the poorer class, only 3·6 gallons were used; model lodging-houses, with every necessary accommodation, required 7·8 gallons. The quantities from Humber are imperial gallons.

These figures are interesting, when viewed in relation to the different

classes of people, and properly characterize the different districts; as the grade of society is higher, the water consumed for domestic purposes increases, and almost, it would seem, in regular proportion.

For the purpose of comparing the foregoing figures with like figures in this city, we have prepared Table IV., in which is shown the relative per capita consumption of water in dwellings inhabited by various classes of society. The quantity of water in each case was ascertained by meter measurement. It appears that the dwellers in flats require abundant water, while the tenants of the "Spencer House Barracks" are quite indifferent to its use.

TABLE IV.

	Class of Building.	Location.	Monthly Rent.	Number of Inhabitants.	Consumption of Water per head per 24 hours.	
					Gallons	Liters.
1	Lorraine, flats........	East Third Street...........	Flats, $15 to $40	68	55·0	208·1
2	Normandy, "	Longworth & Race Sts...	" 13 " 40	72	54·4	204·8
3	Saxony, "	S. W. Cor. 9th & Race Sts.	" 30 " 35	38	46·0	174·1
4	Brittany, "	N.W. " " " "	" 40	72	40·0	151·5
5	9 dwellings..........	Grand St. & Eden Park...	Each 40	52	34·2	129·5
6	12 "	W. Side St. James St.. ..	" 25 to 45	55	27·6	104·5
7	14 "	E. " " " ".....	" 35 " 40	80	25·2	95·4
8	10 "	Calhoun & Madison Sts...	" 20	60	12·9	48·8
9	Tenement house.....	112 Hunt Street............	Rooms, 3	37	12·5	47·3
10	" "	S. E. Cor. Front & Ludlow	" 2.50	137	9·6	36·3
11	Lock St. Terrace, flats	Lock Street..................	Flats, 5 to 13	176	9·0	34·0
12	Tenement house.....	116 & 118 Hunt Street....	Rooms, 3	61	7·1	26·9
13	" "	Spencer House Barracks..	" 2	334	5·8	22·0

The first seven buildings are first-class dwellings in every respect, having all the modern water conveniences. The eighth and eleventh have hydrants on each floor, but no water-closets. The ninth and twelfth are inhabited by Germans, and have the samê water connections as the eighth and eleventh. The tenth has similar connections, with a water-closet on each floor.

It is of interest to note, in this connection, that there are certain dwellings on the hillsides, the lower floors of which are supplied with water, by gravity, from cisterns. In this manner the consumers get clear water. This is appreciated, and it is therefore used economically. It has been found that in houses supplied in this way a cistern, holding 1,500 gallons (5,679 l.), will furnish a family of six persons a supply for a year, or at the rate of seven gallons (26·5 l.) per head per day.

Having now presented an outline of the evils resulting from abuses of

water privileges, and indicated, somewhat, the importance of the prevention of waste, it is proper to point out what has been done and what may be done for the correction of these evils.

The subject of the prevention of waste in Cincinnati has commanded attention from the first establishment of our water system. As early as 1824, only three years after the establishment of the Water Works, the originator and owner of the works, Mr. Samuel W. Davies, assigned as the reason for his inability to supply the town with water, that the consumers were too wasteful; and, at his request, the Council passed an ordinance to correct this evil by the infliction of a fine of $10 for each offense. Mr. Davies was compelled, nevertheless, to shut off, nightly, the water supply for self-protection, notwithstanding the remonstrances of the people. A committee was appointed by Council to inquire into the violation of the charter granted to Mr. Davies and associates in 1817 for the supply of the town with water. In their report they acknowledged the wanton waste of water, but said, in regard to the shutting off at night, that "it has a tendency to seduce the citizens into a fatal security, while the devouring element (fire) spreads its devastating hand." Mr. Davies continued the practice, however, and so did his successors, the Cincinnati Water Company. Council passed other ordinances relating to the wastage of water in 1832, and another in 1854. In 1860, Mr. R. C. Phillips, then Superintendent of the Water Works, considered the subject very fully; and, since his statements are quite interesting and extremely applicable to-day, we give the following extracts from his report.*

"Careful observation and measurements made at the reservoir by the Engineer during the past year, have demonstrated that an amount of leakage, equal to 1,118,080 gallons, takes place in twenty-four hours, or about twenty-two per cent. of all the water delivered to the reservoir. This result was obtained by noting the water between the hours of twelve o'clock, midnight, and three o'clock, morning, when it is assumed there is very little water actually used; he has, however, taken the least fall, and from this minimum quantity deducted twenty-five per cent. for actual or legitimate use.

"I am quite certain that the whole leakage in the street mains, valves, and all other portions of the Works, properly belonging to them, does not amount to two per cent. of the amount delivered to the reservoirs; and, therefore, about twenty per cent. of the whole supply may be charged

* Report Cincinnati Water Works, 1860, 19 – 20.

to leakage and other waste, in and through the small sluice pipes, their valves, hydrants, water-closets, urinals, etc.

"Taking into account the fact that there are probably 18,000 outflows in the city, and that upon an average probably one-third of these are constantly leaking, more or less; that a very small leak, that would scarcely attract attention, will waste from 100 to 200 gallons in twenty-four hours, and that many leaks, in water-closets, urinals, etc., amount to from 400 to 20,000 gallons in twenty-four hours, it becomes apparent that the result above obtained is probably below the truth; for 6,000 leaks, discharging upon an average 200 gallons each in twenty-four hours, will waste 1,200,000 gallons of water daily.

"The total population of the western district of Cincinnati, by the late census, is 160,000. Assuming the average daily delivery as 5,000,000 gallons, gives a daily consumption of 31·25 gallons for each inhabitant.

"Deducting the amount of waste, say twenty per cent., making the aggregate daily supply 4,000,000 gallons, the average consumption for each inhabitant becomes 25 gallons."

We have already quoted the results of the investigations of Mr. Americus Warden into this subject, while Engineer of the Pumping Department in 1875. His report for that year concludes as follows:*

"The preceding remarks and citations, from eminent sources, are offered for your consideration, in order that, in the future, judicious methods and means may be put in practice for the prevention of the enormous loss now sustained by improvident use of water. We are aware that it is difficult to control consumers, and that prosecution for waste of water is productive of vexations, disputations, and expense in time or money; nevertheless, abuse of water license should be punished; for water delivered into the reservoir and transmitted through the service pipes to the consumer, is of intrinsic value and a commercial commodity to be sold under certain restrictions for the benefit of the municipality at large, as well as for the use of the individual consumer; and a license to *use* water in no sense grants privilege to *waste* it."

The means now employed by various water works for waste prevention may be classified as follows:

1. House to house or day inspection. This system is used, with varying results, by all water works.

2. The introduction of meters. This method is the most reliable one for checking waste and is being slowly introduced, especially among large

* Report Cincinnati Water Works, 1875, 76—77.

consumers of water; although the universal adoption of meters is not in the near future. The cities of Providence, R. I., and Fall River, Mass., are the only large cities having anything like a meter system. About one-half of the service branches in Providence have meters attached to them. The annual reports of this city show flattering receipts by meter rates, while the per capita consumption is only 30 gallons.

3. Licensing and regulating plumbers; the inspection and stamping of plumbing work and material, and restriction in the use of water. These important regulations are not enforced in this country; but in Great Britain they are faithfully observed, and have been the main cause of the success there in preventing waste.

4. The Deacon system. This consists in the employment of a waste meter, an invention of George F. Deacon, C. E., of Liverpool, England. The meter is placed on the main water-pipe supplying water to a certain district and records automatically, on an index card, the approximate flow of water at various times of the day and night. The object of the meter is to localize the most wasteful district. Inspectors visit their respective districts nightly, going from stop to stop, shutting off each one, and noting the time. The hydrant key is used as a "stethoscope" for testing purposes. This system has been in successful operation in the city of Liverpool, where it was first introduced. Under an intermittent supply of nine and a half hours' duration per day, the average consumption was about thirty-five gallons per head per day, and when the constant service was turned on experimentally, the consumption rose to over forty-four and a half gallons per head. An unrestricted constant service is now given with an average consumption of twenty-eight gallons per head per day for all purposes; of which eighteen gallons are required for domestic use, and ten gallons for manufacturing and other business purposes.

5. The Bell Waterphone.* Of this last-named means I desire to speak at some length. The device consists of a metallic diaphragm attached to one end of a steel rod, the whole being enclosed in a trumpet-like casing made of gutta percha. A thread is cut on the lower end of the rod. The method of attaching the instrument to the water-pipes for the detection of leaks or waste will be described further on. The principle upon which the device acts is that when attached to a water-pipe it amplifies the wave sounds produced by flowing water to such an extent that the current produced by a mere drip is at once detected.

*A note on the Bell Waterphone appeared in these PROCEEDINGS, 2, 42.

The merits of this instrument lie in its very simple construction, its easy application, its reliability, and its consequent efficiency. It may be applied at the time of day when abuses are most likely to exist and without the knowledge of offenders. It also detects invisible as readily as it does visible leaks. Moreover, under a system where the Waterphone is used, the careful consumer is not molested in any way, and investigation is made only where waste is known to exist. With this instrument an official becomes not only an inspector, but an unerring detective. This fact has a very desirable moral effect, for the certainty of discovery prevents many abuses and causes the prompt correction of leaks that would otherwise have received no attention.

The waterphone system has been in use in Cincinnati for twelve months past, and has proved most highly successful and satisfactory. I can, in no way, give a better understanding of the method of using the Waterphone, and of the good results following its use, than to describe the facts as they are in Cincinnati. The inspector, having been assigned a district, starts to work at eleven o'clock P. M., provided with a formulated record book, a waterphone, a hydrant key, and a lantern. Having found a service-box, he opens it, inserts the key and catches the head of the service-stop, which he turns partly off to lessen the opening through which the water must pass. He then screws the waterphone into the top of the key, and applies his ear to the diaphragm to detect any sounds produced by the flowing of the water through the partly closed service-stop. If a flow exists, however small, he will readily detect it. If no sound is heard, it is conclusive that there is no waste, and accordingly he marks the premises "O. K." in his book. If, however, a sound is heard, he notes whether it is loud or faint. He then turns the stop off entirely, and, if the sound ceases, he marks an "inside" flow—that is, on the premises. If the sound continues, it is then recorded as an "outside" leak—that is, between the stop and the main pipe.

The inspector continues testing stops in this manner until half-past four A. M., when he returns to his home for rest. He reports at the office, after eight A. M., the result of his night's inspection. He then visits the places where flows were detected, to determine the cause. If no visible leak is found, he tests for an underground leak; if this is not found, it is deemed conclusive that the flow discovered was due to a careless or wilful failure to close the tap or cock, and the subscriber to the branch is served with a notice like the following:

ABUSE NOTICE.

CITY WATER WORKS OFFICE.

No............ Dist............

Cincinnati................................188

To the Owner or Tenant of Premises

No..St., b..Streets.

Your hydrant will be turned off for the following cause:

Permitting unnecessary flow of Water in Water Closet.

" " " " of Hydrant.

" " " " of Stop Box.

Unless a fine of $5.00 is paid at this office.

..................................District Officer.

When a leak is located, the following notice is left at the premises:

LEAK NOTICE.

CITY WATER WORKS OFFICE.

No............ Dist............

Cincinnati................................188

To the Owner or Tenant of Premises

No..St., b..Streets.

Your hydrant will be turned off for the following cause:

Permitting Leak in Water Closet. Permitting Leak in Hydrant.

" " Stop Box. " " Lead Pipe in House.

Permitting Leak in Lead Pipe in Ground.

Unless same is corrected within 24 hours and plumber's certificate of repair filed at this office; otherwise a fine of $5.00 will be imposed in addition to turning off water.

..................................District Officer.

A proper record of these notices is kept on the stubs from which the blanks are taken.

It may occur that the outside leak will be heard at several consecutive branches, faintly or loudly at first, and increasing or decreasing as the inspector approaches or recedes from the source of the sound. In such cases, the cause is due to a joint leak in the main pipe. These sounds are dull and rumbling, resembling the roaring heard in a shell or hollow body, while a leak in the service branch, inside or outside, produces a sharp, shrill, and distinct noise.

There are cities, like New York and Boston, where sidewalk stops, such as we have in Cincinnati, are not used, and it would seem that the system of night inspection would, on this account, be impractical. But, happily, the Waterphone Company has devised a plan—in the clamp and wire connection—which is very inexpensive, readily applied, and quite as effective as the outside stop. A clamp is fixed and sealed upon the service-pipe at any accessible point inside the premises, preferably outside of the

private stop. The wire is screwed to the clamp and extended to the outside of the house, where it terminates with a screw-end, fixed to the front wall or the side of the steps. The inspector, on his night rounds, attaches the waterphone to the wire, and through this medium he detects any flow inside or outside of the premises.

Inspectors should be provided with gum or leather washers to replace defective ones, thus correcting on the spot a large number of leaks and avoiding expense and inconvenience to consumers.

The use of this system during the past twelve months, by the Cincinnati Water Works, has detected and corrected the following number of classified abuses and leaks:

Willful abuses in water-closets,	170	
" " hydrants,	211	
" " urinals,	19	
Total,		400
Leaks in water-closets,	389	
" faucets,	726	
" hydrants,	1,107	
" hose plugs,	164	
" lead pipes,	286	
Total,		2,672
Underground leaks in lead pipes,	299	
" " sidewalk stops,	86	
" " hydrant stocks,	1,035	
Total,		1,420
Miscellaneous leaks,		314
Total number of abuses and leaks,		4,806

In addition to the correction of nearly five thousand cases of wastes, many more were stopped without the knowledge of the water authorities, through the influence of these inspections.

The consumption of water for 1882 was 1,271,000,000 gallons less than in 1881, a decrease of fifteen per cent. The per capita consumption was 69·7 gallons for 1882, and 87 gallons for 1881. This represents a saving in fuel alone of $17,000.

The daily average use in 1881 and 1882 was as follows:

TABLE V.

MONTH.	1881.	1882.
	Gallons.	Gallons.
January	18,406,655	17,287,479
February	19,515,450	17,551,835
March	18,892,087	17,493,951
April	19,283,414	19,801,381
May	23,534,065	19,804,432
June	23,484,225	20,685,542
July	28,507,603	21,255,338
August	31,665,708	22,246,513
September	28,871,689	22,004,314
October	25,802,557	21,374,545
November	19,706,973	18,005,442
December	18,056,895	16,809,083
Daily average	23,007,272	19,524,846

Basing conclusions upon the water-rent receipts, the rate charged, and the population of the city, the various uses made of water per capita in Cincinnati are classified as follows:

TABLE VI.

	GALLONS PER 24 HOURS.			
	1879	1880	1881	1882
For general purposes (assessed rents)	26·5	27·0	27·7	28·0
For metered water	5·0	6·7	6·0	8·5
For hydraulic elevators	3·0	4·9	4·0	5·0
For street sprinkling	·7	·8	·6	·7
For charitable institutions, public buildings and free purposes	2·0	2·7	3·1	3·2
Waste	30·8	32·9	45·6	24·3
Total per capita consumption	68·0	75·0	87·0	69·7

The above table shows there has been a legitimate increase in the consumption, but the waste has been reduced from 45·6 gallons per capita in 1881 to 24·3 gallons in 1882. This good work is, as yet, only fairly under way; but the results show clearly what may be accomplished by a systematic waste inspection.

The inauguration of the Waterphone System was accompanied with much opposition, extending even to threats of personal violence. But the public soon found that the water officials would not be intimidated, and in a short time their approbation and encouragement were secured.

The number of willful abuses discovered at the commencement was

startling. They were due chiefly to the thoughtless and common habit of propping up the valve of the water-closet. There were cases where no valve existed or where it was put out of sight, lest some one might stop the flow of water and cause disagreeable odors. Along the hillsides and river a number of supposed springs, some being regarded as landmarks by the oldest inhabitants even, stopped after leaks in neighboring pipes were discovered and corrected. The cause of damp cellars, in some localities, was traced, by the inspectors, to defective lead pipes in the neighborhood.

At the start it was not a rare occurrence to find, posted over the water-closet in many business houses, a sign like this: "Don't stop the water." Now it is quite satisfactory to say that a sign, having just the opposite command, greets the eye.

Before closing, it may not be out of place to refer to a particular case, where a gross negligence of water privileges was displayed. The place in question is a charitable institution, having the privileges of free water. It is supplied with two ⅝-inch service branches, under a head of 120 pounds' pressure. The drains are connected with a private sewer and, are not trap-drains. In order to prevent the disagreeable odors and sickness, the sister in charge of the institution, considered it a paramount duty to let the water run constantly, verily believing that this was one of the water privileges to which they were entitled.

The subject of the wastage of water is a very comprehensive and important one. It is possible, in a paper like this, to touch very briefly only upon but a few of the leading points involved. Since Cincinnati can not be an exception in her experiences, the suggestions and methods regarding waste prevention, as considered in this paper, may be useful to others.

VII.—UTILIZATION OF SEWAGE FROM HILLS.

BY ALFRED R. PAYNE.

[Read before the Section of Mechanics and Engineering, April 24, 1883.]

THE sewage of the city of Cincinnati is carried into the Ohio River, not far below the inlet pipes of the pumps which supply the city with water for all purposes. Mr. Arthur G. Moore, Chief Engineer and Superintendent of the Water Works, referred to this in his recent report, in connection with the proposed purchase of Markley Farm for a water-works site, and used this fact as an argument for making a change, based on the sewage contamination of our water supply during high-water eddies.

When the pumping station was established at its present location, the river was considered to be as free from sewage contamination at that point as at any other. But, owing to the growth and spread of population, and to the fact that the vicinity was chiefly inhabited by a class of persons not distinguished by habits of the greatest cleanliness, the river at this point is by no means a limpid mountain stream.

If a trunk sewer for Walnut Hills is built, the outlet will be in the river, of course, below the present Water Works, and must necessarily further contaminate the river—if not for ourselves, for our neighbors in Covington. It may be difficult to retrace our steps so far as concerns our system of sewerage for the older part of the city; but as we have a large area in the suburbs as yet unprovided for in this respect, why not follow the example of other cities and do something toward solving the question of utilizing our refuse? At present, our only aim is to cast it out.

For years, the city garbage has been taken by a company and turned to profit; can not a profit be derived from the sewage also? In England and other countries this has been done to a large extent, although not, as yet, universally. The solid is separated from the liquid contents, and each treated by a different process; the solid is put into sacks and sold as a fertilizer; the liquid, after the valuable and injurious elements are removed, is allowed to pass off into the river or sea, as clear as water. A chemist of my acquaintance, in charge of one station, told me that those who worked at these stations, and fully understood the process, used the water for all ordinary purposes. The liquid is also sold to florists and market gardeners.

In the city of Amsterdam, Holland, a pneumatic system of Captain Liernur is used. A central depot is provided for each district, where a powerful steam-engine operates air-pumps, exhausting the air from receivers, with which every house is in direct communication; and by a simple syphon device, the suction is brought into operation at each well when full, so that no attention is necessary except at certain central points. Each depot is in charge of a foreman, with workmen under him, who attend to the charges from the receivers; the solid matter is calcined and put into bags for sale; the liquid has the ammonia extracted by distillation, the water is allowed to flow away, and the residue, if any, sold for fertilizer. Mr. Moule, an English clergyman, uses earth or ashes as a substitute for water in a water-closet. A chamber situated under each closet receives a supply of earth or ashes from a hopper above, each time the closet is used, by raising a handle, whereby some of the contents of the hopper are projected into the chamber below, so that a constant

system of disinfection is going on. When the chamber below is full it is emptied, the contents are spread out to dry and are then ready for use again; and are sold, after repeated use, as a most valuable manure. In fitting up a dwelling-house with these closets, they may be arranged to discharge into a brick vault in the cellar, provided with a door for access in clearing out; hoists may be provided communicating with each hopper, so that they can be conveniently filled when empty. The contents of the cellar vault can be dried and used again, without inconvenience. This plan, however, has never been adopted on a large scale, but has been used for villages, hamlets, barracks, manufactories, and public institutions; and the manure disposed of by private arrangement and not by local boards.

In some parts of Europe, the sewage is collected in boxes, from house to house, the collectors leaving an empty box in place of a full one taken away. These boxes are carted to a depot, where the sewage is calcined in ovens; after which it is spread on a floor, broken up, and is ready for sale as a fertilizer. In other places, the sewer discharges upon a meadow, where the sewage is allowed to flow upon one portion, while the other portions are resting. By all the above plans, sewage is utilized.

The city of London has several pumping stations, where the sewage is pumped up and discharged into the River Thames about fourteen miles from its mouth, at high water; and, at the turn of the tide, it flows out to sea. This is an effective means of getting rid of it, and preventing the pollution of the river at London; but in time, by this means, the country would become impoverished. I have visited one of these pumping stations, and, at first sight, thought it belonged to one of the London water works companies, so neat were all the appointments. The building was a model of engineering architecture; the "holy-stoned" floor was protected by matting; all the unpainted iron and brass work was burnished; the engine was of the Cornish type, having a steam-cylinder 120 inches in diameter and fourteen feet stroke—a perfect piece of mechanical skill.

The leakage from the pump stuffing-box alone gave out a slight odor. All this expense was incurred to throw away a valuable product, and much complaint is made of its effect upon the sea at watering-places below London. In early times, when water-closets were comparatively rare, the common privy was built with a pit under it on a level with an ash-pit at the rear, into which ashes and house offal were thrown. When the ash-pit was full, a man came during the night and emptied it—first removing and piling the ashes in a circular heap, leaving a space in the

center into which the sewage was emptied, and left to be carried away by a cistern-wagon. The ashes being taken last, the whole was carried to land owned by the city or town. This method was pursued in my boyhood at Birmingham, England, with a population of about 200,000 people, seven-eighths of whom were unprovided with any other means of disposing of such refuse.

Now suppose the ash-pit had been placed about six feet above the floor level of the privy, and had been provided with apparatus similar to Mr. Moule's closets; all this ash would have disinfected the sewage, and farmers would have been glad to pay from $1·00 to $1·75 per load for the result. It is suggestive to consider how near every householder approached Mr. Moule's valuable discovery, and yet did not make it; and, further, how many cases of typhoid, typhus, and other zymotic diseases were caused among people living in densely populated districts, by breathing this air laden with deadly germs; as, after all, the regulation requiring the work to be done at night simply prevented the smell from being noticed, while the actual evil was probably as great. "Out of sight, out of mind," was well illustrated in this case. We all know how interested children are in all that is passing around them, and I have seen crowds of them gathered about a catch-basin while men were removing its foul contents by means of a bucket and rope.

In any discussion of the sewage of the high hills environing this city, it must be remembered that we have to deal with a population on Mount Auburn and Walnut Hills of about 32,000, whose solid offal would amount to, say, seventy-two tons daily. The liquid would be about 1,006,000 gallons, with a fall at either of our hills of from 350 feet to 400 feet to the river into which the sewer will empty.

With these points before us, I will briefly outline what I think is a practical solution of the problem.

We have unimproved lands, near the summits of all our hills, which can be acquired at small expense. I would erect on these lands a suitable plant for filtering all the sewage and separating the liquid from the solid matter, as fast as it runs to the works—the sewers being all built with an inclination towards this point or into a main collecting sewer. After the liquid has been properly treated, it should be allowed to run off from the works by means of pipes erected from the bottom to the top of the hills, say three pipes, ten inches in diameter, to allow for excessive flows during rain-storms. These pipes should be arranged so that one or more could be in operation, according to the requirements of a large or small volume of liquid. There would be thus ready for use, a water

power equal to forty-three, or more, horse-power, according as all or only one of the pipes are in use; this power would operate a turbine, and could be transmitted by a wire rope to the top of the hill to drive the machinery for treating the sewage; or could be let to manufacturers—the sewage flow being equal to about one and one fourth times the water supply. The value of the treated sewage is estimated at about $2·50 per head per annum, or $80,000 for this population.

The sanitary aspect of the question is, of course, far above any other consideration; and that some idea may be had of what may be done, I will close by saying that the average reduction in mortality effected in twelve towns in England, by a more perfect sewerage system, was nineteen per cent.

I am indebted to Mr. Waring's work, "The Sanitary Drainage of Houses and Towns," for some of my facts and figures.

NOTE.—At Newport, R. I., the death-rate up to 1870 was 34·16 per 1,000; reduced, in 1873, to 25·76 per 1,000, after steps had been taken to improve the sewerage. At Middletown, a small place, with the population more scattered, the proportion was 8·38 per 1,000. Worthing, England, since the sewerage has been removed from the dwellings, has the lowest death-rate recorded for a city, being only 14·5 per 1,000, which corresponds with an average duration of life of 69 years. In 1872, the loss of time from sickness in Massachusetts averaged 17 days; and for the previous 8 years, 14 days. Out of 19 persons per 1,000 who die yearly, 4 could be saved by a proper system of drainage. The financial loss for Massachusetts is $1,500,000 per annum.

VIII.—MECHANICAL PUDDLING.

BY J. G. DANKS.

[Read before the Section of Mechanics and Engineering, February 27, 1883.]

MY purpose in this paper is not to treat on the science of puddling generally, but merely to sketch the history of mechanical puddling, the difficulties encountered, and the manner in which they have been overcome.

It is necessary first to describe briefly the old or hand system of puddling, as it may assist in understanding the difficulties to be met in performing the work by machinery. Puddling is the process in most general use for converting cast into wrought iron, by first melting, and then agitating the metal while kept at a high temperature; in which operation it is deprived of its carbon, silicon, and other impurities.

The process was first introduced by Henry Cort, in England, in the year 1780. In partnership with Samuel Jellico, at Fontley in Southampton, he worked out this problem, which was at that time the most important step ever taken towards increasing the quantity and reducing the

cost of manufacturing iron. A reverberatory furnace was used, which consisted of a fire-grate, puddling chamber, and flue, covered with a fire-brick roof, and separated from each other by bridge-walls, which, though high enough to confine the iron and fuel in their respective chambers, allowed a free passage of the burning gases from the fire-grate to the puddling chamber, and thence through the flue to the chimney proper, provided with a damper by which the puddler controlled the temperature of the furnace, and, to some extent, the character of the flame.

The bottom and sides of the puddling chamber in Cort's furnace were lined with sand; and, as the removal of silicon is one of the chief objects of the puddling process, it will be readily seen that one of his worst enemies (sand) was present at all stages of the operation.

Notwithstanding this, the advantage of his invention, to the manufacturing interests of England, may be partly seen by the following figures. The total amount of iron manufactured in 1720 was about 12,000 tons, and at the time of Cort's patent—1780—about 90,000 tons, which in 1820 had increased to 400,000 tons, an increase due almost exclusively to Cort's invention. Although he had added millions of pounds sterling to the wealth of the kingdom, and opened the way for the employment of hundreds of thousands of men, the only recognition his services received was the empty honor of being a great inventor and the little estate now occupied by his moldering remains in Hampstead Churchyard.

The first important improvement subsequently made in puddling was the invention of Samuel B. Rogers, consisting in the substitution of iron plating to the bottom and sides of the puddling chamber, covered to a depth of ten or twelve inches with a rich oxide of iron, instead of sand. The plates are so constructed as to allow a free circulation of air, to prevent overheating. This oxide bottom not only permits the working of the iron at a much higher temperature than was possible on the sand bottom, but is itself a valuable agent in the removal of the carbon, silicon, phosphorus, and other impurities contained in the crude metal.

The invention of Rogers was fully as important to the trade as that of Cort, yet the most substantial benefit we hear of his receiving was the nickname of "Old Iron Bottom," by which he was known all over England.

But little change has taken place in the process of puddling by hand since the latter invention was introduced; and although it is, in a scientific point of view, one of the most interesting operations in iron manufacture, it is also the most slavish and exhaustive labor to those engaged in it.

The earliest authentic records I find on mechanical puddling are the patents of Mr. Walker and Mr. Warren, of England, who, in the year 1853, took out a patent for a rotating cylinder lined with fire-brick. The axis of the cylinder was inclined to a horizontal axis of rotation, so that, as it revolved, the fluid metal was caused to flow from one end to the other. I am not aware that they ever built a furnace so as to test their ideas in practice.

In 1856, Mr. Samuel Danks (the writer's father) filed a caveat in the U. S. Patent Office for a revolving puddling furnace, and he had a furnace nearly completed in Mount Savage, Md., when the panic of 1857 caused the abandonment of the work for the time.

In 1859, Mr. W. Tooth, of London, England, took out patents for a mechanical puddling furnace, and was given every facility for testing the apparatus by Mr. William Menelaus, of the Dowlais Iron Works in Wales, where a complete forge was erected, and some good iron is said to have been produced. The lining used in these furnaces was either fire-brick or gannister, and Mr. Menelaus stated that the latter was found to be the best material he had tried. In 1863, Mr. Tooth and a Mr. Yates obtained additional patents for improvements in the process, all of which were tested at the Dowlais Works. In 1867, after having spent upwards of $150,000 in experimenting, it was abandoned. Mr. Menelaus, in a paper read before the Institution of Mechanical Engineers, gave a description of their failures, which were mainly due to the want of a good lining for the puddling chamber. Afterwards, when showing a number of prominent iron masters through the Dowlais Works, he pointed to the corner occupied by these furnaces as the "burying-ground of mechanical puddling."

It is important to notice that up to this time the only lining used in mechanical puddling was a highly silicious one (like that used by Mr. Cort in the first introduction of hand puddling), which would be readily dissolved by the molten metal and the oxides with which it was constantly coming in contact. Under these circumstances it was found to be practically impossible to remove the impurities from the metal sufficiently to insure a good fibrous iron. Nor was this all; the character of the lining material was such, that when the iron was formed into a ball, its weight constantly broke the lining down, so that it was proved to be unfit to withstand either the chemical or the mechanical action to which it was of necessity subjected.

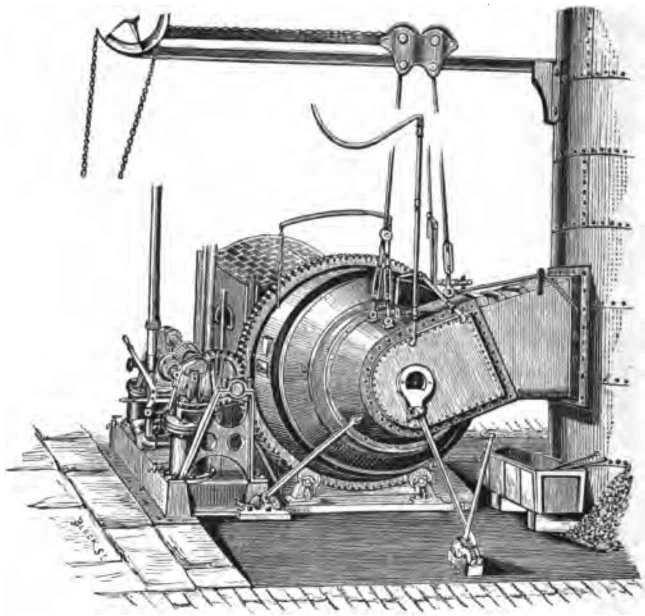
An attempt was made to use an oxide-of-iron lining in the cylinder; but from the manner in which it was poured in it was evidently an oxide

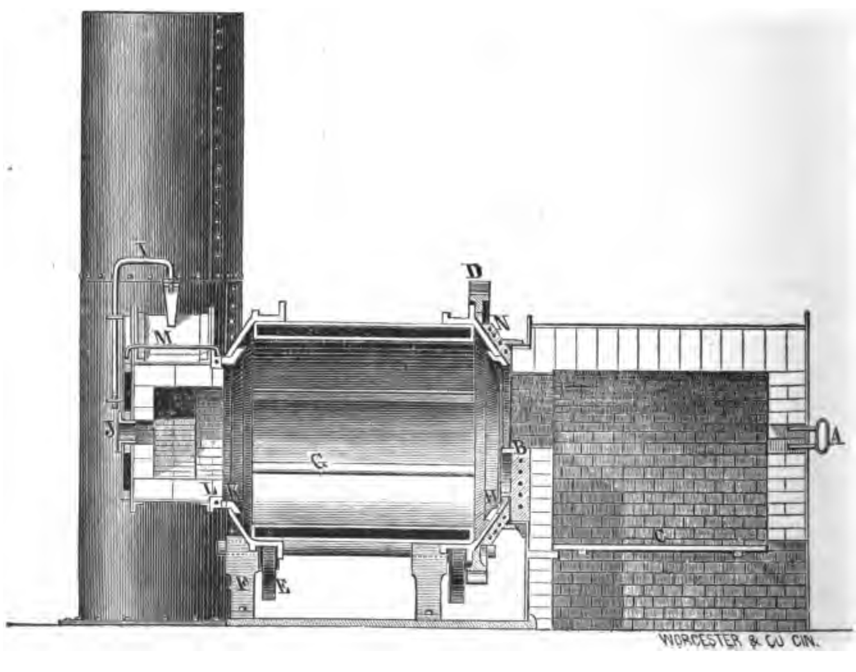
too high in silica for the purpose; or, if an oxide of sufficient purity were melted upon an initial lining of silica, sufficient of the latter would be dissolved during the melting to render it worthless.

During the time when these experiments were being carried on in England (between 1863 and 1868), Mr. Danks moved to Cincinnati, Ohio, to remodel the old merchant mill on East Front Street, and adapt it to the manufacture of iron rails. Here he again revived the question of mechanical puddling, and had obtained patents for a lining which, it was believed, would answer successfully all the requirements of use.

In May, 1868, a small experimental furnace was built, with a capacity of working only about 300 pounds of iron at one charge, being thus limited by the machinery at hand to deal with the iron. Six hand-puddling furnaces were in use in the mill at this time, with the usual complement of workmen; and while the new furnace was approaching completion, the comments made by those engaged in the hand process were not encouraging, for they were, with few exceptions, opposed to any attempts to perform their labor by machinery.

Briefly, the new furnace (which is fairly illustrated in the cuts on the next page) consisted, first, of a fire-place about four feet square, the outer shell of which was made of iron plates, lined with fire-brick. Adjacent to this was the revolving cylinder, about three feet long and four feet in diameter, with a contracted opening at each end. One end of the cylinder was made to fit close against the fire-place, and the other end provided with an adjustable elbow-piece, forming a tight joint with the cylinder end and also serving as a connection between the cylinder and the chimney, by which the waste gases escaped. The cylinder was mounted on four rollers, the end joints kept tight by a strong iron prop which forced against the shiftable elbow-piece, the latter being also provided with a side prop holding it firmly in position while the furnace is at work. The cylinder ends were kept cool by jets of water. The bridge casting, the bridge and door rings, also the front of the shiftable piece, were kept cool by water circulating through them. The fire-place was provided with a bridge-wall reaching half-way up the opening in the cylinder end, to prevent a mixture of the fuel and iron, but leaving a free passage for the gases through the furnace. The fire-grate was also provided with two blast-pipes, respectively, for forcing air underneath and over the fire. The bottom blast entered the ash-pit and found its way up through the burning fuel. The top blast entered an air-space formed over the roof of the furnace, and was admitted to the furnace proper through a finely perforated brick arch, as nearly over the bridge-wall as possible.

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Each blast-pipe was provided with a valve, under the control of the puddler.

The advantages of forced blast in this form of furnace are many; chief among them are, first, a higher temperature than can be obtained by natural draught; and, second, that a slight pressure of flame may be kept in the furnace which prevents the entrance of cold air at the cylinder joints, thereby avoiding not only a reduction of the temperature of the furnace, but a waste of iron by oxidation.

The cylinder plates were ribbed on the inside so as to hold the lining, and the machine was rotated by a small steam-engine. When everything else was ready, and the cylinder revolved a number of times, the lining was put in. This was done by first mixing pulverized Iron Mountain ore into a stiff mortar with about six times its bulk of thick lime-cream in a grinding mill, consisting of a revolving pan and two heavy iron rollers, and with this material covering the ribs of the cylinder plates to the depth of one inch, making an average thickness between the ribs of four or five inches. The lower half of the cylinder was first lined, a good surface being put on it with a trowel, and the whole was then thoroughly dried, by building upon it a wood fire. The cylinder was then turned a half revolution and the lining completed and dried. This was called the initial lining, and was only used to protect the plates while the real or working lining was put in.

The furnace being now fired up slowly, a quantity of roll-scale or hammer-slag was first melted so as thoroughly to glaze the initial lining. A large quantity of pulverized ore and some light wrought scrap were now put into the cylinder and melted—the cylinder having been revolved slowly during the melting. After melting, the rotation was stopped and a quantity of dry lumps of ore thrown into the bath, serving the double purpose of presenting a rough surface to assist in agitating the iron, and also to hasten the cooling of the liquid oxide. After hardening sufficiently, a further quantity of ore and scrap was thrown in and melted; this operation, being repeated about five times, usually completes the lining. The vitreous coating thus formed is very hard, and I never knew of its breaking down after once being cooled, except at the openings at the ends of the cylinder, where it is thin. The lining gradually wears away, but it is easily repaired, and the entire lining need never be taken out unless for some necessary repairs to the plates.

When the furnace was put to the test of puddling iron, the ridicule so lavishly heaped upon it by the men ceased, a lively competition ensued, and it became evident that they had laughed too soon; for the machine

had not been in operation many days before it produced seven charges of iron in less time than they could produce six by hand, and required less than one-fourth the amount of manual labor, although employing the same number of men. The quality of the iron was found to be superior in every respect to that made by hand.

This furnace was experimented with for some time, and then, with the view of puddling larger heats and still utilizing the old machinery, two larger ones were built, in which the diameter of the cylinders was about the same, but the length increased to about six feet, it being the intention to divide the charge into two or more balls. This was attempted by leaving apertures in the cylinder plates, through which pieces of soapstone or other refractory material could be inserted, for the purpose of breaking the iron asunder as the furnace revolved. Large lumps of iron ore were left projecting high above the general level of the lining; cast-iron projections, covered with a thin layer of the initial lining, were inserted, but all gave a good deal of trouble, and were finally abandoned as impracticable.

In carefully watching and testing the product of these two furnaces, a much more serious difficulty presented itself. In a cylinder so long in proportion to its diameter, the end next to the fire-grate was always much hotter than the other, and the iron at this end was always the best, thus producing two qualities of iron in each charge. Added to this lack of uniformity (which was not met with in the small furnace) was the labor of separating the iron. There seemed no way left to adapt the system to existing machinery; in fact, experience indicated that the farther we departed from the old method of making the iron into a number of small balls, the better would be the results. Accordingly, furnaces were built with cylinders six feet in diameter and four feet six inches long, in which the entire charge was made into one ball. With slight alteration, the old squeezer was made to take these balls of 600 pounds, and the iron was found to be perfectly uniform. The results obtained were so satisfactory, that in 1870 the company authorized the removal of all the hand-puddling furnaces as fast as machines could be built to replace them.

One result constantly met with was the subject of much unfavorable comment among those who had not investigated the subject. It was the fact that, instead of the usual loss of from ten or fifteen per cent. in weight by hand puddling, there was a gain of from five to eight per cent.; that is, out of 500 pounds of pig iron charged into the furnace, there was obtained in puddled bars from 525 to 540 pounds. The gain often ran up to ten per cent., but the figures given will represent a fair average.

I will now describe the operation of puddling by machinery, in which we will find, at least, a partial solution of the above mentioned seeming impossibility. Puddling is essentially a refining process, and as the refining is best accomplished while the iron is in a fluid state, a grey pig is preferable to a white pig, because it may be kept fluid as long as desired, this property being chiefly due to the amount of silicon it contains. White iron, which usually contains a low percentage of silicon, begins to granulate very soon after melting, unless a large amount of phosphorus is present.

The refining agent used in puddling is an oxide of iron, and a quantity of the latter is usually put into the furnace, in the shape of hammer cinder, squeezer cinder, or roll-scale, with each charge of iron. As soon as they are melted, the furnace is started to revolve slowly, the iron being covered by a bath of liquid oxide. To facilitate the operation, a small jet of water is now thrown, by means of a rubber hose, upon the descending side of the furnace lining, immediately above the liquid iron. This chills a part of the oxide, which, adhering to the lining, is carried down through the iron, oxidizing the silicon, phosphorus, and such other impurities as the iron may contain, and these become incorporated with the cinder. It is interesting to watch these changes taking place. The iron, which at first was quite fluid and somewhat resembling quicksilver, becomes gradually thicker, until, when the refining is complete, it has entirely lost its silvery appearance and comes to the consistency of thick paste or mortar, its melting temperature having materially increased. The bath of oxide, on the contrary, has become more fluid, and *its* melting temperature *decreased.* This operation is carried as far as possible without causing ebullition. The temperature is now raised so as to thoroughly liquefy all the oxide, which is now removed from the furnace through a tapping hole. When this is done, the furnace is again put in more rapid motion so as thoroughly to agitate the iron. Up to this point the iron has retained a large part of its carbon, which is now rapidly oxidized by the lining of the furnace and causes violent ebullition. The iron has now reached the granulated state and occupies five or six times the space it did when fluid. The carbonic oxide gas, produced by a union of the oxygen of the lining and the carbon of the metal, presents a beautiful appearance as it bursts through the surface in many hundred jets of pale blue flame.

When carbon is burned by free oxygen, it has no effect in reducing oxide of iron; but when the carbon is oxidized by the solid oxides of the furnace lining, the oxide containing it is reduced to the metallic state and

is added to the charge; and as from 300 to 600 pounds of iron ore are used (in the shape of lining) for every ton of iron produced, it must be the iron reduced from this lining which increases the charge and makes it greater than the original weight of pig iron. It is believed by many that silicon has this power to reduce oxide of iron to the metallic state; and it is a fact, well established, that iron containing a high percentage of silicon gives a better yield than iron containing but little silicon, although the carbon in both cases may be the same. The boiling operation usually lasts from ten to fifteen minutes, when the grains of iron unite, forming a spongy mass, which is then removed from the furnace to be squeezed, hammered, or rolled into bars, as may be required.

There were in 1870 and 1871 three forges built to puddle iron by this method—one each in Chattanooga, Indianapolis, and Pittsburgh. In the two former the furnaces and engines were poorly constructed, and, after working for about one year, the defects of building and abuse while working made the repairs so heavy that they were finally abandoned. The plant of ten furnaces in Pittsburgh is still in successful operation.

In 1871, Mr. Danks visited England, and, by invitation, read a paper before the Iron and Steel Institute, at a meeting held in Dudley, giving a description of his furnace. This resulted in the selection of a commission of three gentlemen to visit Cincinnati and investigate the subject. The scientific part of the inquiry was entrusted to Mr. George J. Snelus (at that time in the employ of the Dowlais Works), the commercial aspect of the system to Mr. John A. Jones (Ironmaster of Middlesbrough), and the practical working to Mr. John Lester (of Wolverhampton). They came over in October, 1871, bringing with them about forty tons of English pig iron and iron ore, containing good, bad, and indifferent qualities, all of which were carefully marked. The lining was all taken out of one furnace and a lining of English material put in. Samples were taken from each brand of pig iron for analysis; also, samples at different stages of the operation during puddling. They weighed all the material used and the iron produced. The examination was a very searching one, and the results fully accorded with our own previous experience. They visited Indianapolis and Chattanooga, where furnaces were at that time in successful operation. (Those in Pittsburgh were not then completed.) I omit reference to their report on account of the length of this paper, which already exceeds the limits of the mere sketch intended.

In February, 1872, the first furnace on the Danks system in England was put in operation, at the works of Messrs. Hopkins, Gilkes & Co., in Middlesbrough. Specimens of the iron produced were severely tested,

and exhibited at the quarterly meeting of the Iron Trade. The excitement ran high, and a public invitation was given for the Iron Trade to visit the works in a body on a certain day to see the furnace in operation. In the meantime, a written contract was entered into with the inventor to pay a certain price for the right to use 200 furnaces; the contract was signed by Mr. Menelaus, on behalf of the manufacturers, and the day fixed for payment. But when the day came, it brought disappointment to the inventor; for, through the efforts of one or two members who had been unsuccessful workers upon this same problem, the contract was repudiated. Many members openly condemned this disgraceful proceeding, and four firms obtained licenses to build furnaces which would puddle 1,000 pounds at a charge. Two of these firms met with the same fate as their predecessors at Indianapolis and Chattanooga, and from the same cause. I have no recent information as to whether the others are now working; but in 1878, Messrs. Hopkins, Gilkes & Co. produced with their six furnaces over 10,000 tons of machine-puddled iron, on all of which they realized a handsome advance in price over the iron puddled by hand, owing to its superior quality.

Soon after the starting of our first furnace in England, and the practical demonstration of the successful working of the machine, others entered the field, using our lining and cooling advantages without asking permission; among them were Mr. Adam Spencer, of West Hartlepool, and Mr. Crampton, of the Woolwich Arsenal. Mr. Spencer built an immense furnace, the cylinder of which was about ten feet long, and in which he worked one ton of iron at each charge. He met with the same trouble we had found in the long cylinder, and failing to obtain a uniform result, soon abandoned it.

Mr. Crampton made a new departure in trying to adapt pulverized fuel to the revolving furnace, in 1872. His furnace was a long cylinder with a water jacket, the shell being made double, and a large stream of water circulating through it. The cylinder was divided into two compartments—one of which was intended as a combustion, and the other as a puddling chamber. This evidently did not give good results, as the double cylinder was soon replaced by a short single one, and the fuel blown directly into the puddling chamber. The heat obtained is said to have been very intense, but the foreign matter in the fuel impaired the quality of the iron to such a degree that it had to be discontinued.

Dr. C. W. Siemens has used the revolving furnace extensively for the manufacture of iron direct from the ore. A description of the process would unduly lengthen this paper.

On March 5, 1872, William Sellers, of Philadelphia, obtained patents for a revolving puddling furnace, in which one end of the cylinder was entirely closed and the gases made to enter and leave through different flues at the open end. The closed end of the cylinder was provided with a large trunnion, by which its rotation was effected and also part of the weight carried, instead of a shiftable flue, by the removal of which access was had to the cylinder. The cylinder and engines were mounted on a pivoted frame, and could be turned at a right angle from their working position. I have no information as to the results obtained with this furnace, but believe none of them are now in operation.

The report of the English Commission made plain the fact that iron of an inferior quality could be rendered sufficiently pure by the process of mechanical puddling to be used in the open-hearth steel process, instead of the expensive charcoal bloom now used. Nothing of importance was done in that direction (in this country, at least) until about one year since, when the Otis Iron and Steel Company, of Cleveland, took up the matter under the direction of Mr. Samuel T. Wellman, Superintendent of their works.

Their scientific man and also a practical iron-worker were sent to Cincinnati, where our furnaces were at work. Samples were taken back for analysis, and, soon after, they purchased the right to build a furnace capable of puddling one ton at each charge. The cylinder of this furnace is built of steel plates strongly riveted together, and is six feet six inches in diameter and same length. The fire-grate is fitted with our automatic stoker.* The furnace has been in operation about six months, and the product put into steel with such favorable results that others are now in process of erection.

It would require a large volume to record all the perplexing problems that have presented themselves to those engaged in perfecting this system. The point which perhaps gave most trouble was the abrasion ring at each end of the cylinder. These rings are not only subjected to a good deal of friction as the cylinder revolves, but also to unequal expansion and contraction. It was important that they should be kept cool; and if the workman neglected to keep water turned on, they became hot, and, in cooling, became cracked, so that if a large stream of water was turned on, part of it ran into the furnace. The requirements of the case called for a ring which should stand the friction without wearing too fast, and be of such material as would stand repeated heating and cooling; and

* Described in these PROCEEDINGS, 1, 118.

constructed in such a manner that no matter how much water was turned on, it could not get into the furnace. About twenty-five different modifications were tried, both in wrought and cast iron, and considerable time was required to test their respective merits.

The ends of the first cylinders were straight-faced instead of conical; and when the furnaces were cooled down on Saturdays, the lining was found to have a number of cracks varying from one-eighth to three sixteenths of an inch in width, due to shrinkage. During the repairs to the brick-work, these cracks became filled with fine dust; and when the furnace was heated again, they could not close up, and the expansive force was sufficient to break the cylinder plates, though they were provided with heavy wrought-iron bolts and bands. This suggested the conical ends, which were found effectually to remedy the difficulty.

So, indeed, it might be said of nearly every detail of the present mechanical puddling furnace—all have been suggested by experience; and, although many of the furnaces first started have been discontinued, the work of the past ten years has not been in vain, for progress, though necessarily slow, has been sure; and it may be safely affirmed that the mechanical puddling furnace of to-day is not only a durable, but an economical machine.

The full benefits of mechanical puddling will not be realized until it has almost entirely abolished the present plan of making pig iron for mill purposes. The fluid metal will be taken directly from the blast furnace to the puddling machines, where it may be worked in charges of one ton each; and the spongy ball, after having been squeezed into a compact bloom, say of fifteen inches diameter, taken directly from the squeezer to a powerful universal mill, and either reduced to a bar from ten to fifteen inches wide and one inch thick, or, if desired, made into a square billet of any size down to five or six inches; the bars cut and piled in lengths required for different purposes; the billets sheared and taken, while hot, to a heating furnace, where, with a wash-heat, they may be rolled into any small sections required, without the intermediate process of piling, nor having been allowed to cool, in one continuous process from the time the ore is first heated until it is bar iron ready for market.

Working under such conditions as these, a product of ten or twelve tons can be relied upon from each machine every twelve hours (instead of one and a half tons made by hand) and of a quality far superior to that produced by the old system.

IX.—DEVELOPMENTS IN THE KINETIC THEORY OF SOLIDS, LIQUIDS, AND GASES.

By H. T. Eddy, C. E., Ph. D., University of Cincinnati.

[Read before the Section of Chemistry and Physics, April 26, 1883.]

Part I.—A Further Application of the Theorem of the Virial to the Kinetic Theory of the Atomic Vibrations within a Molecule of Gas.

In a paper upon *An Extension of the Theorem of the Virial, Etc.*,* the author has expressed the opinion that, "since an elastic connection is neither a degree of perfect freedom nor of perfect constraint, but something intermediate, there is no whole number of degrees of freedom in the system" of atoms constituting a molecule. Mr. H. W. Watson, in a letter to the writer dated April 2, 1883, has shown that this language is open to objection; for degrees of freedom are so defined as to include not only what I have termed degrees of perfect freedom, but also all degrees of imperfect constraint.

The object of this paper is to make a more careful comparison of the distribution of energy among the co-ordinates expressing the possible degrees of freedom of a molecule, and thus show, as is asserted in the paper referred to, that "in case partial constraints not amounting to the loss of entire degrees of freedom are introduced with respect to any of the co-ordinates, the energy will no longer be equally distributed among the co-ordinates, but will be influenced by these constraints."

As this is in direct contradiction to the conclusions derived from the discussion of the distribution of energy by the method of generalized co-ordinates, which has been supposed to prove that the mean kinetic energy with respect to each co-ordinate is the same, it will be further necessary to make an examination of a point in the received theory from which this contradiction arises. It will then appear that the contradiction is due to an error, which has heretofore escaped notice, in the method of employing the fundamental expression for the distribution of velocities among the co-ordinates.

We shall first consider the distribution of energy among the co-ordinates expressing the degrees of freedom in a gas, each of whose molecules consists of two atoms. We do this because the simplicity of the system enables us to avoid mathematical difficulties; while, at the same time, the

*These Proceedings, **2**, 26-43, March, 1883, or
Franklin Inst. Jour. [3] **85**, 339, 409. 1883.

demonstration that this case is in contradiction to the received theory will show that theory to be in error as conclusively as if a more complicated case were chosen for discussion. For the same reason, the atomic forces will be assumed to be elastic, without thereby impairing the cogency of the demonstration.

Furthermore, for the sake of simplicity, let the two atoms constituting each molecule be in all respects equal, and let the gas be perfect—*i. e.*, let the molecules have no mutual attraction. If the two atoms be supposed to be rigidly joined together and held at a small fixed distance asunder, and if they form a molecule which is a smooth solid of revolution, then the molecule has five degrees of perfect freedom, which may be taken to be three of translation along rectangular axes and two of rotation about a pair of equal principal axes of inertia.

The theorem of the virial, as developed in the paper previously referred to, would agree in this case with the method of generalized co-ordinates in ascribing to each of these motions a mean kinetic energy per unit of mass represented by the expression $\frac{1}{2} pv$, thus making the mean total kinetic energy per unit of mass to be $\frac{5}{2} pv$, in which expression p and v denote specific pressure and volume.

As introductory to a further discussion of this case, let us compute the mean total energy by regarding the atoms themselves as material points, having each three degrees of freedom of translation, but constrained by such forces as will bind them together fixedly in pairs. The theorem of the virial is then expressed by the equation:

$$\tfrac{1}{2} \Sigma_0^n m (x'^2 + y'^2 + z'^2) = \tfrac{3}{2} pv + \tfrac{1}{2} \Sigma r R, \qquad (1)$$

in which m is the mass of each atom, n the number of atoms in a unit of mass, x'^2, y'^2, z'^2 are the mean squares of the velocities along the rectangular axes of $x y z$, r is the constant mutual distance of the pair of atoms in any molecule, and R is the mean value of the force needed to retain them at the fixed distance r in case the rigid connection were removed. Since the encounters are regarded as very nearly instantaneous, the mean value of the impulsive forces vanishes, and consequently the mean value of the force along the line joining the atoms of a molecule is simply the mean centrifugal force. Now the distance of each atom m from the center of gravity of the molecule is $\frac{1}{2} r$, and if the mean squares of the angular velocities about a pair of axes, through the center of gravity and perpendicular to the line joining the atoms be ϕ'^2 and ψ'^2, then

$$R = \tfrac{1}{2} m\, r (\phi'^2 + \psi'^2), \qquad (2)$$

$$\therefore \tfrac{1}{2} \Sigma_0^n r R = \tfrac{1}{4} \Sigma_0^n m\, r^2 (\phi'^2 + \psi'^2), \qquad (3)$$

The value of this quantity has been computed in my previous paper,

equations (23) and (25), in which, in order to make them agree with the present case, we must put

$$A = 0, \quad B = C = 2\, m \left(\tfrac{r}{2}\right)^2. \tag{4}$$

$$\therefore \tfrac{1}{4} \Sigma_0^n\, m\, r^2 (\phi'^2 + \psi'^2) = pv, \tag{5}$$

$$\therefore \tfrac{1}{2} \Sigma\, m\, (x'^2 + y'^2 + z'^2) = \tfrac{5}{2}\, pv, \tag{6}$$

the value before given for the total mean kinetic energy. Let this system now be supposed to have an additional degree of freedom, as follows: Let the connection between the atoms of a molecule be supposed to be perfectly elastic, but let its modulus of elasticity be so large that the mean centrifugal force can only change the mean distance between the atoms by an amount $2\delta r$, which is some very small fraction of r. Let us compute, at first, the effect of the centrifugal forces alone, and neglect the direct impulsive forces acting along r during the encounters; it will afterward appear that the character of the result we shall arrive at will remain unchanged when these are also taken into account. The mean distance of each pair of atoms will be increased under the action of the centrifugal force from r to $r + 2\delta r$. As a part or the whole of this force may come into action suddenly at an encounter, or at any instant when a sudden change of rotary velocity occurs, each atom will oscillate about its mean position under the action of an elastic force whose mean maximum value is the mean centrifugal force

$$R = m\, (\tfrac{1}{2}\, r + \delta r)\, (\phi'^2 + \psi'^2), \tag{7}$$

and at a distance whose mean maximum amplitude is δr. The equation of the virial, as applied to this case, may be written in the form

$$\tfrac{1}{2} \Sigma_0^n\, m\, (x'^2 + x'^2_1 + y'^2 + y'^2_1 + z'^2 + z'^2_1) = \tfrac{5}{2} pv + \tfrac{1}{2} \Sigma\, R\, \delta r, \tag{8}$$

in which x'^2, y'^2, z'^2 have the same signification as in (1) and (6), while $x'^2_1 y'^2_1 z'^2_1$ denote the mean squares of the additional velocities along $x\, y\, z$, which are imparted to an atom by reason of its oscillation and increased distance. But R and δr are to be taken as variables, so that in computing the value of $R\, \delta r$ in the last term of (8), it is to be taken as the mean value of that product during the oscillation. Now, the value of this product is known from the laws of elastic vibrations to be one-half the product $R\, \delta r$ when the maximum values of R and δr are employed. Hence by (7)

$$\tfrac{1}{2} \Sigma_0^n\, R\, \delta r = \tfrac{1}{4} \Sigma_0^n\, m\, \delta r\, (\tfrac{1}{2} r + \delta r)\, (\phi'^2 + \psi'^2), \tag{9}$$

in the left hand member of which R and δr express mean values, but in the right hand δr is the maximum value of that quantity.

Now, neglecting terms of the second order of small quantities, (9) becomes

$$\tfrac{1}{2}\, \Sigma_0^n R\, \delta r = \frac{\delta r}{8r}\, \Sigma_0^n\, m\, r^2\, (\phi'^2 + \psi'^2). \qquad (10)$$

$$\therefore \text{ by } (5),\ \tfrac{1}{2}\, \Sigma\, R\, \delta r = \tfrac{1}{2}\, pv \frac{\delta r}{r}. \qquad (11)$$

Hence (8) becomes, on substituting the values of the summations given in (6) and (11).

$$\tfrac{1}{2}\, \Sigma_0^n\, m\, (x'^2_1 + y'^2_1 + z'^2_1) = \tfrac{1}{2}\, p\, v\, \frac{\delta\, r}{r}, \qquad (12)$$

the first member of which expresses approximately the mean energy of motion with respect to the degree of freedom which the molecules of a unit of mass of gas have along r. The approximation consists in this, that in neglecting terms of the second order no account is taken of the fact that the atoms are at a slightly greater mean distance while under the action of the centrifugal force. But this fact of an increased mean distance constitutes the sole difference between the impulsive action of the centrifugal force and any other impulsive forces which might cause the atoms to oscillate about their positions of equilibrium. Hence it appears that if oscillations are also caused by impulsive forces acting along r at the instant of an encounter, or if oscillations already existing in a molecule are not destroyed at the instant of encounter, but instead all the oscillations caused in whatever way are superposed and combined together, equation (12) still correctly expresses the ultimate value of the energy along r, provided δr is the amount of the mean maximum displacement of each atom from its mean position, due to all causes combined. Equation (12) then is general in case of diatomic molecules, and shows with the greatest distinctness how the energy of a degree of freedom which is an almost complete constraint is related to the energy of a degree of perfect freedom, *i. e.*, freedom without constraint; it shows that for equal temperatures in a given perfect diatomic gas, the mean energy of this degree of freedom is directly proportional to the magnitude of the relative displacement of the atoms caused by any given force; *i. e.*, the mean energy is inversely proportional to the molecules of elasticity along the line joining the atoms, and in case this modulus is large the energy with respect to this degree of freedom is to that of a degree of perfect freedom as δr to r.

The case computed in the previous paper, where it was shown that in an imperfect gas, *i. e.*, in case there are small intermolecular forces, the energy with respect to the rotary co-ordinates differs slightly from that of those of translation was a case of very slight constraint, but equally conclusive as to the fact to be established that any partial constraint affects the relative amount of the mean energy of that degree of freedom.

Furthermore, it appears that equation (12) applies equally to the atoms of complex molecules, and is not restricted in its application to diatomic molecules; for it only requires that the atoms shall be drawn toward their mean position by elastic forces, and as it is well known that all elastic vibrations are but the superposition of linear vibrations to which equation (12) applies, it may also be correctly applied to any combinations of such vibrations. In case the molecules contain atoms of different kinds the summation must be taken for each kind separately.

We will now consider the more general case in which the force with which the atoms of a molecule are drawn toward their mean position differs somewhat from that of the direct first power of the displacement. It is easy to see that in this more general case, an expression similar to (12), in which the coefficient of the right-hand member differs somewhat from $\frac{1}{2}$, will represent the actual relations with sufficient exactness. This will appear from the following discussion of oscillatory motion under the action of forces arbitrarily made to vary according to some assumed law.

Let a ball, suspended as a pendulum, be in contact on either hand, in its position of equilibrium, with small fixed elastic rods, whose inertia may be neglected in comparison with that of the ball. Upon communicating an impulse to the ball in the direction of the length of the rods, one of them will be compressed; and an oscillation will ensue, in which the force of restitution will be that of the direct first power of the distance. In order that the force should be different on the two sides it is only necessary to make the rods unlike.

If it be desired to represent some other law of force, increasing at a rate greater than the first power of the displacement, it is only necessary to have each rod enclosed in a thin elastic tube slightly shorter than the rod and sliding freely on it, and this tube again in another and so on. By sufficiently increasing the number of such tubes, and appropriately varying their cross section and length, any law of force may be reproduced with as great exactness as is desired. This is intended rather as a physical representation to the mind, as to how any law of force may be built up out of single forces varying as the first powers of displacements whose origin are not coincident, than as a practicable device. Now considering the energy of the vibration of the ball so far as concerns a single pair of tubes on opposite sides of the ball, it only differs from that with respect to the rods by the fact that there is a short free space between the ends of the tubes, in which the ball will be free from their influence. The effect of this will be to somewhat increase the

mean kinetic energy, for it causes the motion to approach more nearly to the case of oscillation between two fixed elastic walls, a case in which the mean potential energy vanishes and the total energy is kinetic. This case could then be represented by (12), by somewhat increasing the coefficient $\frac{1}{2}$. Similarly, in case the force increases at a less rate than the first power of the displacement, the coefficient in (12) must be made less than $\frac{1}{2}$.

We may, then, broadly state the conclusion which we have now sufficiently demonstrated, that the energy of interatomic vibration depends upon the atomic displacement within the molecule, and in such a way that when this is a vanishing quantity with respect to the dimensions of the molecule, the energy of the interatomic vibration—*i. e.*, of internal vibration of the molecule—is a vanishing quantity with respect to the energy of motion of the molecule as a whole.

But this conclusion, as was stated in the earlier part of this paper, is in disagreement with those drawn from the treatment of the question by the method of generalized co-ordinates, as may be seen by consulting Boltzmann* and Watson.†

Now the theorem of the virial determines the mean value of the energy with respect to any co-ordinate by finding directly its average value for a single molecule during such an interval of time as may be necessary in order to obtain a correct mean value. The method of generalized co-ordinates, on the other hand, determines, in the first place, the law of distribution of velocities among all the molecules constituting a given mass of gas in equilibrium. This law is the same for every co-ordinate, and agrees with that of the most probable distribution errors in the theory of least squares, being, in fact, the most probable distribution of velocities as to each co-ordinate. The required mean kinetic energy is then obtained by taking the average value at any given instant for all the molecules in the mass of gas under consideration.

As is well understood in the theory of least squares, there is in the expression for the distribution of errors an undetermined constant which depends for its value upon the observations themselves; so likewise there is an arbitrary constant in the expression for the distribution of velocities which is dependent, as is usually stated, upon the temperature, or, as it may be better expressed, upon the mean kinetic energy with respect to the co-ordinate under consideraiton. Let u be the velocity with respect to any co ordinate; then the law of distribution of velocities states that

*Ueber der Nature der Gasmolecule, Sitzb. der Wien. Akad. Bd. 74, 1876.
†Kinetic Theory of Gases, pp. 37 and 41.

when the whole number of molecules considered is n, the probable number having a velocity between u and $u + du$ is

$$dn = n\sqrt{\frac{h}{\pi}}\, e^{-hu^2} du, \tag{13}$$

in which h is the arbitrary constant, which must be determined by observation—*i. e.*, by the condition that the mean kinetic energy as to this co-ordinate shall agree with the actual fact; thus, if $\frac{1}{2}m\overline{u^2}$ is the mean energy, then h is to be found from integrating the equation

$$\overline{u^2} = \frac{\int e^{-hu^2} u^2\, du}{\int e^{-hu^2} du}, \tag{14}$$

in which the limits are $+\infty$ and $-\infty$.

Now, it has been heretofore assumed that h has the same value for each of the co-ordinates in a gas in equilibrium, which is equivalent to assuming outright that the mean energy is the same for each co-ordinate. The fact is that h must be separately determined for each co-ordinate solely from the condition that the mean kinetic energy as to that co-ordinate shall agree with the fact in nature. The error is precisely similar to that which would be committed in the theory of observations, if sets of observations made under different circumstances were assigned equal weights. It must first be shown that they have equal weights before they can be so combined; and in the case in hand it must be shown that the various co-ordinates are similarly circumstanced with respect to the fortuitous molecular encounters occurring, before it can be assumed that the total energy will be distributed, on the average, equally between them. Until such a proof is given, it can not be assumed, and the computations made in this paper and in the one previously referred to sufficiently show the untruth of the assumption. The question then arises as to how the kinetic energy is distributed among the various degrees of freedom, and what law does it follow. This is the question which I have endeavored to answer so far as I have found it possible in this and the previous paper. From (12) it has appeared that the intermolecular vibratory energy is small, and depends upon the displacement. In the previous paper it is shown how the intermolecular forces affect the relative energy of translation and rotation. From the discussion of these extreme cases, in one of which the constraint is almost a vanishing quantity and the freedom almost perfect, and in the other the constraint is almost complete and the freedom almost nothing, it will be clear that

we have established what it was proposed to show, viz.: that distribution of the kinetic energy depends upon the forces acting, and is not independent of them, as has been assumed.

PART II.—KINETIC CONSIDERATIONS AS TO THE NATURE OF THE ATOMIC MOTIONS WHICH PROBABLY ORIGINATE RADIATIONS.

THE assumption that the mean kinetic energy of translation of the molecules of a gas is the measure of its temperature is one whose beautiful agreement with experiment has led to its acceptance as a necessary part of the kinetic theory of gases, and it has often led to the thoughtless conclusion that this translatory motion is also the mechanical source of the disturbances in the ether which originate radiations. But there are many difficulties in the way of accepting this view. One of the first and perhaps the least is the difficulty of conceiving how such a motion of translation, which is essentially longitudinal, can originate a lateral vibration such as light and radiant heat must be.

A greater difficulty appears to be found in the extremely moderate mean velocity of translation which the molecules of a gas are found to have. Molecular velocities which are of the same order of magnitude as that of sound or of a rifle ball seem hardly fitted to cause the necessary compressions or disturbances in a medium in which the rate of propagation is so immense. Or, to state it in another way, if molecules in describing their paths originate radiations, then the motion of a rifle ball ought also to do so, or indeed any much more moderate motion, such as that of a vehicle or animal.

A still further difficulty is that there is another part of the kinetic theory which appears to be so related to this that both can not be rigorously true at the same time, which appears in the following manner: The most probable distribution of the component molecular velocities of a gas in equilibrium is the same as that of errors of observation. This distribution is brought about by fortuitous molecular encounters, and its permanence is insured by reason of them. But in case the progressive motion of a molecule gives rise to radiations, those molecules whose velocities are the greater are the hotter, and consequently radiate more heat to other molecules than they receive from them. They therefore lose part of their progressive energy before the next encounter. The whole effect would be to retard the motion of those molecules whose kinetic energy is greater than the mean and accelerate those whose kinetic

energy is less. This would cause a constant interference with the distribution of velocities according to the law of probabilities; and the interference would, so far as we are able at present to form an estimate of its amount, be sufficient to cause the kinetic energy of each molecule to approach indefinitely near its mean value during the time in which it describes a very small fraction of the mean path between successive molecular encounters. If this is the case, the kinetic energy of any molecule is in effect the same during the whole path, and there is no such distribution of velocities as has been assumed. In case the interference with the assumed law is not as complete as this, it must nevertheless exert an important influence upon the distribution of velocities, especially in the case of rarefied gases, in which the encounters are comparatively infrequent.

Again: if the progressive motion of the molecules can originate radiations consisting of transverse vibrations, it would appear highly improbable that their rotary motion should not also do the same. But as has been shown in another paper,* the kinetic energy of translation differs from that of rotation for imperfect gases, and the temperature can not be simply proportional to the rotary energy, though it might possibly be proportional to the sum of the rotary and translatory energies combined. But aside from these difficulties, which may serve to show the intrinsic improbability of the hypothesis that the progressive motion of the molecules originates radiations, we seem to reach pretty decisive evidence against the hypothesis when we consider the specific heats of solid bodies, or when we consider the nature of the radiation itself as revealed by the spectroscope.

The experimental law of Dulong and Petit and the analogous results of Neumann, show that in solid bodies we must consider the temperature to be measured more nearly by the energy of the atom than by that of the molecule. Now it is hardly supposable that the translatory motion of a gaseous molecule should originate radiations while that of a solid should not.

We shall not at this stage of the discussion consider the spectroscopic evidence as to the nature of the motions which originate radiations further than to notice that the characteristic spectra of gases appear wholly inexplicable on the supposition that they are originated by translatory motions with velocities distributed according to the law of probabilities or with velocities reduced by radiation to an approximate equal-

*An Extension of the Theorem of the Virial, etc. These PROCEEDINGS, 2, 26–43, March, 1883.

ity, as it has been shown they might be; for even the simplest gases have a spectra consisting of at least several lines.

If these reasons compel us to distrust the hypothesis that radiations originate in the progressive or rotary motions of the molecules, does the hypothesis that the vibratory motion of the atoms in the molecule with respect to each other is their source, afford a better explanation of the facts? Such a motion, analogous to the elastic vibrations of a bell or other sonorous body, might very readily perhaps be shown in case of a complex molecule to have such a relation to the molecular impacts and thus to the mean kinetic energy of translation that its energy would be directly proportional to it for each given gas. In case this were established, such vibrations, considered as the physical cause of radiations, would explain the phenomena of gases as well as the supposition that they are due to the progressive kinetic energy; and they might possibly be shown to explain those of solids also. But there is at least one difficulty in the way of accepting this supposition, which seems insuperable in the case of monatomic molecules; for if radiations could only originate in the vibrations of atoms with respect to each other within the molecule, monatomic molecules could not radiate heat at all, and could not have a temperature. That this should be true is not only inconceivable, but contrary to the known fact that monatomic mercury gas has a perfectly ascertainable temperature. Hence the motions which originate radiations are not confined to such vibrations of atoms, even if it be possible that such vibrations do originate radiations. And this consideration leads us to what appears to be the truth of the matter, which is that the atoms themselves are in a state of internal vibration. As will be seen subsequently, this internal vibration is no doubt accomplished under the action of internal forces which permit extremely small deformations only of the atom by any external forces which can be brought to bear upon the atom; *i. e.*, the modulus of elasticity of an atom is very large indeed, and very large, no doubt, when compared with that of the molecule. Indeed, if such vibrations exist within the atom itself, it is not difficult to prove that the force which binds the parts of an atom together (and consequently its modulus of elasticity) is much greater than the chemical force binding atoms into a single molecule. For it has been shown in connection with equation (12) in the first part of this paper, that the amount of energy which can be imparted to a system like this is inversely as the modulus of elasticity. But chemical atoms are bodies which we are now supposing to be in internal vibration, but to which it has been found impossible to communicate energy in amount sufficient to cause

them to fly to pieces. Since they do not become decomposed, while molecules do under various circumstances, it must be that their modulus of elasticity is much larger.

This view accords with that of Lockyer,* who has endeavored to explain the coincidence of lines in the spectra of different elements, and the relation of temperature to spectra by the hypothesis that the so-called chemical elements are merely molecules which have never yet been decomposed by chemists. It must be admitted that the experimental evidence he brings forward is of a very cogent character, and it seems to me that the demonstration by which I have shown that the mean energy of such a vibration would be extremely small, explains how such a vibration can exist without decomposing the more complex atoms, even at the highest artificial temperatures; though Lockyer has reason to think that they are decomposed in the hotter stars, where only the spectra of the elements of low atomic weight are to be found.

Were it true that every degree of freedom must have the same kinetic energy, we could not admit the possibility of such a vibration; for not only would such large amounts of energy be required by the degrees of freedom which seem certainly to exist between the atoms of complex molecules as to entirely contradict experimental values of the specific heat, but the supposition of additional degrees of freedom within each atom would require an amount of energy on the whole many times the actual specific heat of such bodies. But when the amount of heat required by such degrees of freedom is nearly a vanishing quantity, as I have shown, there is nothing to prevent us from assuming that to be the truth which spectroscopic evidence makes most probable. We may notice, in passing, that the general principle upon which this paper rests, that vibrations of this character can exist without absorbing an appreciable amount of kinetic energy, enables us to explain at the same time the extremely moderate rate at which exchanges of heat take place between bodies by radiation. They become only very slowly of the same temperature, which fact needs explanation, in view of the extremely rapid propagation of radiations themselves.

Now, according to our hypothesis, during a molecular encounter the

* Discussion of the Working Hypothesis that the so-called Chemical Elements are Compound Bodies. *Nature*, **19**, 197, 225; January 2 and 9, 1879. Necessity for a New Departure in Spectrum Analysis. *Nature*, **21**, 5, November 6, 1879.

It should be stated, in justice to Professor F. W. Clarke, that this "working hypothesis" was previously proposed by him. See "Evolution and the Spectroscope," in *Popular Science Monthly*, **2**, 320–326, January, 1873.

molecules are roughly shaken, and there is a determinate distribution of energy to be found among the atoms of a molecule at its conclusion, in the form of internal atomic vibration; which distribution is due to the circumstances of the encounter. Those atoms which by chance have more energy than others radiate more rapidly, and since the velocity of radiation is so great and the atomic distance so small, we may assume that the several atoms each acquire almost instantly an energy of internal vibration sensibly equal to the mean, so that in a gas this is their condition during almost the entire free path of a molecule. In case the gas is becoming cooler by radiation to surrounding bodies, the atoms which radiate to these bodies lose more of this vibratory energy than they otherwise would, and thus have less mean energy of internal vibration than they should have under the law of distribution which determines what fraction this energy shall be of the mean kinetic energy of the molecules. At the next encounter the atoms receive their proper share of the mean kinetic energy, which being partially lost by radiation is again supplied, and so on; and because this transformation into internal atomic vibration must take place before it can be radiated, and because at the same time the energy of this vibration is but an inappreciable fraction of the total kinetic energy, the process of exchange by radiation is on the whole slow. Were, however, the translatory motion the direct cause of radiation, the exchanges between diathermous bodies must apparently be nearly instantaneous.

Having now sufficiently cleared the field of inquiry by this preliminary discussion, we come to a closer consideration of the proposed hypothesis, both as to what it is precisely and as to how far it is in accordance with the phenomena.

The whole outcome of Lockyer's investigations, to which we have referred, leads to the conclusion that atoms of the chemical elements are complex bodies, all of which are formed of ultimate atoms of the same kind, so that on this hypothesis there is but one kind of substance from which all others are compounded. Chemical atoms are like a chime of bells all cast from the same material, but each having its own special series of harmonic vibrations.

A necessary result of this would be that the atomic weights should all be exact multiples of some fraction of the atomic weight of hydrogen; which would include Prout's hypothesis, that the atomic weights are simple multiples of that of hydrogen, as a particular case. The experimental data are perhaps not yet sufficiently precise to enable us to obtain a very trustworthy result as to the probability of the truth of Prout's

hypothesis; yet Clarke's* results as to the atomic weights seem to show that the hypothesis has a high degree of probability.

If the chemical atoms of all bodies are assumed to be formed of ultimate atoms which are in all respects equal and alike, this hypothesis furnishes a basis for investigation at once definite and simple, some of whose consequences we shall now endeavor to show to be in accordance with experimental facts.

We wish, in the first place, to show that this hypothesis will make the temperature of a gas proportional to its mean kinetic energy. A chemical atom may be assumed to be a perfectly elastic body, as its deformation is assumed to be extremely small. But, according to the mathematical theory of elastic impact, "when two such bodies come into collision, sometimes with greater and sometimes with less mutual velocity, but with other circumstances similar, the velocities of all particles of either body, at corresponding times of the impacts, will always be in the same proportion."† From this it is clear that in a mixture of two kinds of gas, as hydrogen and oxygen, for example, when the mean velocity of the molecules is so increased that the vibration of the ultimate atoms of the hydrogen is increased a certain per cent., then that of the ultimate atoms of the oxygen is increased by the same per cent. But the circumstances of the encounters and the forces acting between the ultimate molecules determine what fraction the mean kinetic energy of vibration of the ultimate atoms shall be of the mean kinetic energy of the molecules whose encounters cause these vibrations. Since the circumstances attending the encounters are dependent simply upon the forces acting between ultimate atoms, assumed to be in all respects equal, the energy of their vibration will be the same in an atom of hydrogen as it is in an atom of oxygen; for each degree of freedom of every ultimate atom of either the oxygen or the hydrogen is similarly circumstanced, both as regards forces between itself and the other ultimate atoms of the same chemical atom, and also as regards the impacts of other molecules. The proposition of the kinetic theory, which makes the energy of each degree of freedom the same, which has been erroneously applied to the degrees of freedom of molecules, can, therefore, be correctly applied to the ultimate atoms.

But it might not, at first glance, be apparent whether these vibrations are caused by and are proportional to the mean progressive energy of

*Constants of Nature, Part V. A Recalculation of the Atomic Weights, Washington, 1882.

†Thomson & Tait's Nat. Phil., 1867, Art. 302.

the molecules or to their rotary energy combined with it. But it is not difficult to show that the vibrations of the chemical atoms with respect to each other is proportional to the mean progressive energy alone, and then to show the same for the ultimate atoms. Although we have, for mathematical purposes, considered the centrifugal forces as causing vibrations of the atoms with respect to each other, yet, in fact, the vibrations so caused are vanishing quantities compared with those caused by the component of the impulsive force acting during an encounter along the line joining the atoms of a molecule. The amount of a vibration, other things being equal, depends upon the suddenness of the impulse; and the suddenness of the centrifugal force called into play during a change of rotary velocity, by deviation from motion along a tangent, to motion in a circle, can bear no comparison to the suddenness of a direct impulse along the radius of the circle. Hence the direct impulse due to the progressive motion need alone be considered.

We have, then, shown that the energy of vibration of chemical atoms with respect to each other in a simple gas is proportional to its mean progressive energy. The same is true of the vibrations with respect to each other of the ultimate atoms which form a chemical atom, and for the same reasons; for the forces which act upon the ultimate atoms are the impulses due to the encounters of other molecules and those due to the remaining chemical atoms of the same molecule. The energy of the latter of these motions is proportional to the former, as has just been shown; hence their sum is so also; therefore, the energy exerted to deform a chemical molecule and set in vibration is proportional to the mean progressive energy.

But it is to be noticed that the impulses due to the vibrations of the chemical atoms within a molecule are vastly more frequent than the molecular impulses; and it appears probable that the vibrations of the chemical atoms which are set up during an encounter will rapidly decay, even in case they do not directly originate radiations themselves. The vibratory energy of this kind may then be changed almost instantly into that of vibration of the ultimate atoms. According to the hypothesis which we are now considering, the temperature of the body and intensity of the radiation depend solely on the vibratory energy of the ultimate atoms; but since these atoms are assumed to be in all respects equal, they vibrate under the action of the same forces and have the same degrees of freedom and constraint within the chemical atoms of one element as they do within those of a different element. Hence it appears that, if the ultimate atoms of two different gases have the same vibratory

energy—*i. e.*, cause radiations of the same intensity, so that the flow of radiant energy is the same from all ultimate atoms of each gas—then there will be no disturbance of this equilibrium when these gases are mixed, and the distribution of energy is effected by molecular encounters which distribute equal mean amounts of energy to each molecule, instead of by radiations which distribute equal mean amounts of energy to each ultimate atom.

In attempting to account for the high specific heat of liquids, I have elsewhere given reasons for supposing that it is due to a certain per cent. of dissociation which increases with the temperature; but in a gas it seems probable that, although a certain small amount of dissociation may exist, it is not likely to be present in so large amount as in a liquid, nor necessarily to increase with the temperature; since, by reason of the free progressive motion in a gas which does not exist in a liquid, any dissociated atoms have a much better opportunity to recombine; and as the velocities (especially those of free atoms) increase with the temperature, the opportunities increase as well as the number of dissociations occurring in a unit of time; so that, at a high temperature, an atom of gas may not stay dissociated so long as at a lower temperature, while in a liquid this interval will not be sensibly affected by the temperature. That the amount of dissociation present in a gas is small is also in agreement with the view previously advanced as to the rapid decay of internal vibrations in a molecule—at least until they are reduced to a mean value. Complete dissociation, however, will take place at a temperature such that the mean energy of this kind of atomic vibration exceeds the energy of the chemical forces; so that the temperature of dissociation of atoms is completely analogous to the critical temperature at which the cohesive forces can no longer hold molecules together, as has been explained in my paper respecting vaporization, etc.

Perhaps the strongest direct evidence in favor of the proposed hypothesis as to the kind of vibrations which originate radiations is found in the fact that even the simplest elements, such as hydrogen (which is taken to be relatively simple by reason of its low atomic weight) and mercury gas (considered to be simple because its molecules consist of one atom each), have spectra of several lines at least, which goes to show that the source of the light they emit must be a body sufficiently complex to be capable of vibrating in a number of different ways, such as may well be possible for an atom formed of a number of ultimate atoms, but such as is inconceivable in a molecule consisting of one or two perfectly hard

atoms, such as those of hydrogen, mercury and other gases have been assumed to be.

NOTE UPON A PAPER ENTITLED "AN EXTENSION OF THE THEOREM OF THE VIRIAL,"* ETC.

It is stated in connection with equation (45) that the work expended against interatomic atomic forces vanishes during an increment of temperature. This is incorrect; for, although dr nearly or quite vanishes, as is there stated, when dr represents the mean increment of the atomic distances within the molecule, yet this manner of computing the value of ΣRdr is incorrect in case of interatomic forces; for in this case dr should be taken to be the displacement of an atom from its mean position, and it has been so considered in the first part of this paper. This correction does not affect the conclusions obtained from (45).

In a letter dated April 6th, Mr. S. H. Burbury, M. A., has called my attention to the fact that equations (29) to (35) are not sufficiently general to prove the second law of thermodynamics for gases in general. I hope to make a more complete discussion of this matter at some future time. In the meantime I may be permitted to refer the reader to the valuable investigation of the second law as derived from the kinetic theory, which has been given by Mr. Burbury,† from which the insufficiency of equations (29) to (35) will be apparent.

*These PROCEEDINGS, **2**, 26–43, March, 1883.

†Philos. Mag. [5] **1**, 61, Jan., 1876, or Watson's Kinetic Theory of Gases, p. 46.

[*To be continued.*]

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VOL. II. SEPTEMBER, 1883. NO. 3.

SCIENTIFIC PROCEEDINGS

OF THE

Ohio Mechanics' Institute.

PUBLISHING COMMITTEE.

ROBT. B. WARDER, *Editor.*

LEWIS M. HOSEA. JAS. B. STANWOOD.

OHIO MECHANICS' INSTITUTE,
DEPARTMENT OF SCIENCE AND ARTS.
CINCINNATI, OHIO.

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SCIENTIFIC PROCEEDINGS

OF THE

OHIO MECHANICS' INSTITUTE.

VOL. II. SEPTEMBER, 1883. No. 3.

X.—MECHANICAL NOTES.

BY HARRY M. LANE.

[Read before the Section of Mechanics and Engineering, April 24, 1883.]

I. FRICTION OF SLIDE VALVES.

IN discussions relating to the best form, proportions, and number of ports for steam engines, two points have frequently been considered, namely: the frictional resistance to steam in entering and leaving the cylinder, and the area of the cooling surface with which the live steam comes into contact after the surface has been exposed to the reduced temperature of the exhaust. It seems important that we should also consider the power required to move the valve covering the port or ports of the particular form, dimensions, and number, which a consideration of the first two points may lead the designer to adopt.

To show at a glance the relative value of various port arrangements, when measured by the power required to operate their valves, the novel method represented by the accompanying diagram has been adopted.

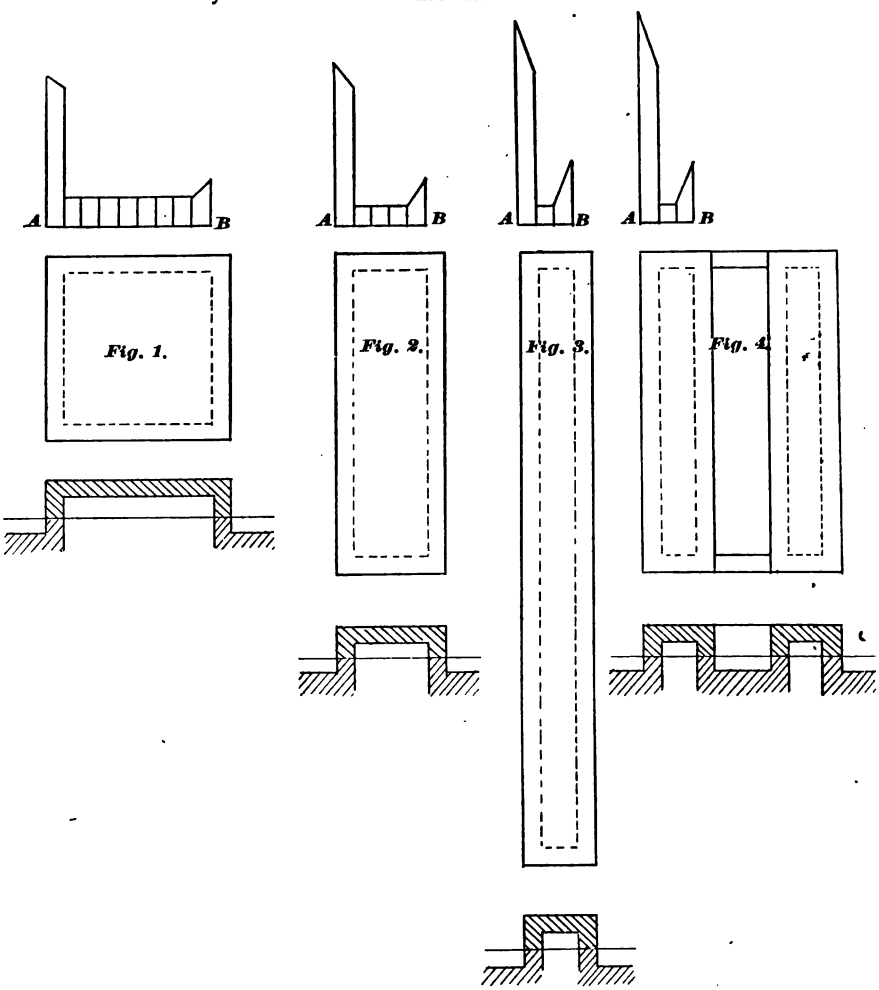
Five different arrangements have been selected, which indicate all principal variations in proportion and number.

The port area is four square inches in each case, and other dimensions are as follows:

Fig. 1.—One port, square, 2 x 2 inches.
Fig. 2.—One port, oblong, 1 x 4 "
Fig. 3.—One port, " ½ x 8 "
Fig. 4.—Two ports, each ½ x 4 "
Fig. 5.—Three ports, " ½ x 2⅔ "

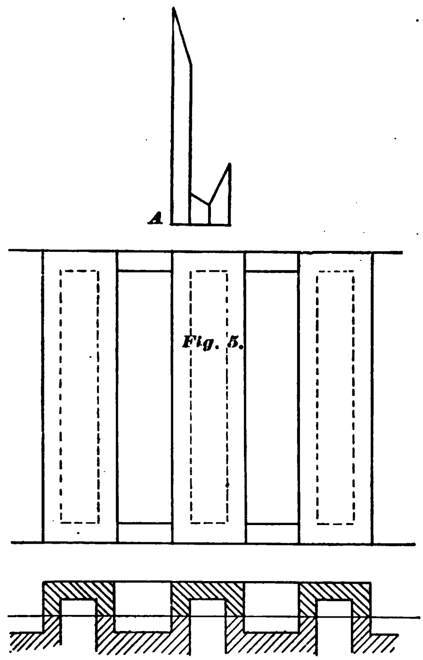
Actual steam pressures are ignored, as being unnecessary, since comparison only is desired. The mean unbalanced area of the valves, multiplied by the travel, is taken as the basis for calculation.

The travel of the valve is represented by horizontal, and the unbalanced area by vertical measurements.



AB is the travel line in each case, divided into ¼ inch spaces. On vertical ordinates is laid off the unbalanced area of the valve at the corresponding point of its travel. Each square inch of such unbalanced area is represented by a linear inch. The area of the completed figure represents the comparative power or work required to move the valve through its stroke, and the length of any vertical ordinate represents the

comparative force required to move the valve at the corresponding point of its stroke. These values, multiplied by the steam pressure (with proper reduction for the opposing effect produced by back pressure) and by the coefficient of friction, give the absolute values of work and force required.



In engines of recent design, the general tendency seems to be toward an increase in the number of steam ports. From this diagram, however, we learn that diminished frictional resistance follows a lengthening of port and reduction of travel in the single port arrangement, and the same improvement is noticed in reducing the number by increasing the length in the multiport or "gridiron" arrangements. In addition to the disadvantage of requiring increased power to drive the valve, it will be noticed that the cooling surface and resistance to entering steam are also greater in the gridiron type. It therefore seems reasonable to conclude, that the greater the departure from the long single port, which admits of short valve travel, the greater will be our departure from attainable excellence.

II. THE SLIDE-VALVE AS A WATER RELIEF VALVE.

It is customary, in plain slide-valve construction, to allow free play of the valve between the collars or within the yoke by which it is driven, for the purpose of allowing it to be lifted from the seat, and thus to serve as a water relief valve, should the quantity of water in the cylinder render this necessary.

To estimate the cylinder pressure necessary to accomplish this, a sketch has been prepared (Fig. 6), showing a slide-valve in the position it would occupy when in the act of relieving the cylinder of water. The dimensions are from an actual engine of recent construction.

To lift the valve requires that the total pressure of the confined water

in the cylinder, acting vertically upwards, at the middle of the width of the steam port, multiplied by its leverage, shall be in excess of the pressure in the steam-chest acting vertically downwards at the middle of the length of the valve, multiplied by its leverage. In the diagram, let

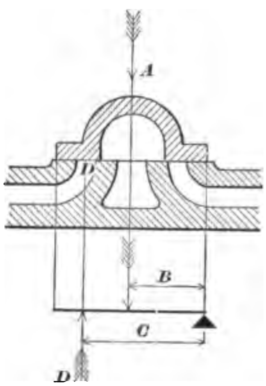


Fig. 6.

A = total pressure of steam in chest acting vertically downwards at the middle of the length of the valve;

B = half the length of the valve;

C = distance from middle of steam port to corner of valve;

D = total pressure in cylinder acting vertically upwards against area of steam port necessary to support the valve.

Then, neglecting the weight of valve, C: B:: A: D or $\frac{B \times A}{C} = D$. In this case we have $\frac{3\frac{3}{32}'' \times 5220}{5\frac{1}{8}''} = 3151$. Dividing this pressure by the area of the port in square inches we find $\frac{3151}{6 \cdot 7} = 508$ pounds per square inch in the cylinder necessary to lift the valve and release the water.

Now it is customary to proportion the fastenings of cylinder heads etc. to resist the highest probable boiler pressure, allowing of course a proper factor for safety. It is evident that the required strength should be based upon the pressure required to lift the slide valve; as the area of the port is relatively small, this may be five times the boiler pressure.

III. COMPRESSION AND CUSHION.

The two terms "compression" and "cushion" are often used indiscriminately in steam engineering. According to Webster, compression is the act of forcing the parts of a body into close union or density by the application of force, and cushioning is the act of providing a soft resting-place. We can not do better than accept these definitions as indicating the distinction which it is desired to point out.

The nature and extent of compression are shown by a diagram from one end of the cylinder; its independent effect is purely economic, in that it increases the pressure and temperature in the clearance space, preparatory to the introduction of live steam, of which it is supposed to save an amount represented by the volume and pressure of the compressed

exhaust. The object of cushion is to bring the reciprocating parts gradually and gently to a state of rest at either extremity of the stroke, or to prevent "pounding on the centers"; we may have, in the same engine, and at the same time, an abundance of compression but absolutely no cushion.

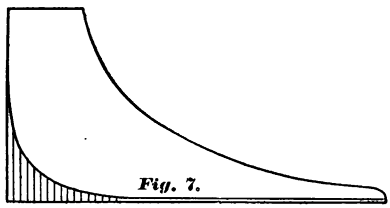


Fig. 7.

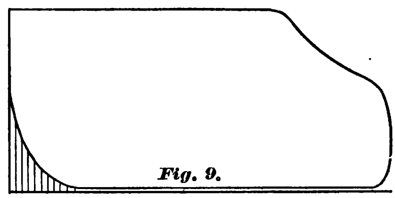


Fig. 9.

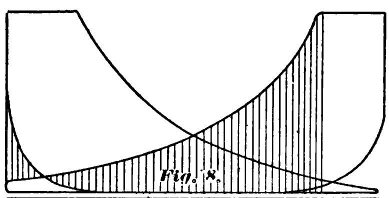


Fig. 8.

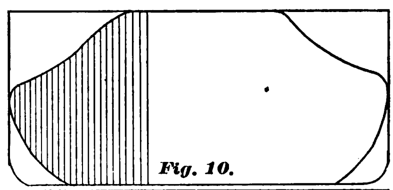


Fig. 10.

It has been stated that the nature and extent of compression may be ascertained by means of a single diagram from one end of a cylinder. In order to derive correct information concerning cushion, simultaneous diagrams from both ends of the cylinder must be referred to. By means of these, we ascertain the pressure on both sides of the piston at every point of its stroke; and it is the difference in pressure on the two sides that we must consider when studying the question of cushion.

The difference in pressure is readily ascertained from diagrams (reversed on the same paper as they are usually taken) by measuring from the steam line of one diagram to the exhaust line of the other.

If we begin anywhere near the middle of a pair of diagrams, or say previous to the fall of pressure due to the cut-off, and measure frequent vertical ordinates toward either end, we notice that the effective pressure is nearly uniform to the point of cut-off. It then becomes gradually less until we reach the exhaust closure of the other diagram, from which point the lines rapidly approach one another, until finally they meet and cross. Now at this point of intersection, the steam pressures on both sides of the piston are equal, and from this point our cushion begins; for the preponderance here changes from one side of the piston to the other.

The pressure (which now becomes cushion, or pressure acting in opposition to the direction of motion of the reciprocating parts) gradually increases, and offers an increasing resistance to the progress of the piston; until, if properly arranged, it will bring it gently to rest at the end of the stroke.

It is with the divergence of the two lines of the diagram from their intersection that we are concerned when considering the question of cushion.

In Fig. 7 we have an indication of the compression; but from this alone, no means of judging of the cushion. In Fig. 8, which represents a double diagram in all respects equal to Fig. 7, we have the deficiency of the single diagram supplied, and from it we may determine the cushion. Fig. 9 affords all necessary information concerning the compression of an engine with a later cut-off, and Fig. 10 (a double diagram from the same) shows the existence of compression without cushion; the intersection of the two lines, indicating the equalization of pressure on the two sides of the piston (which indicates the point from which compression begins), does not occur until the completion of the stroke; instead of that gradual divergence of the lines, as in Fig. 8, we have the lines separating in diametrically opposite directions, due to the rise of pressure occasioned by the incoming live steam on one side of the piston, and the fall of pressure occasioned by opening the exhaust valve and relieving the pressure from the opposite side; the combined effect is a blow on the piston represented by the sum of the increase and decrease of pressure.

It seems probable that confusion concerning the independent effect of the two operations under consideration may account for many cases of pounding; for a sufficient compression, as shown by a single diagram, is generally accepted as evidence that no alteration of exhaust valve action would prove a remedy in case of a pounding engine.

XI.—TARTRATES OF ANTIMONY.

By Charles Seth Evans, B. S.

[The substance of this paper was presented before the Section of Chemistry and Physics, April 26, 1883, and was embodied in a graduating thesis for the University of Cincinnati.]

This paper will deal chiefly with the simple tartrates, including their history and my own experimental investigation.

I.—HISTORY.

Berzelius describes two salts, in his *Lehrbuch*, 5te Aufl., **3**, 1124. He calls the first "tartrylsaures Antimonoxyd," and gives it a formula equivalent to $Sb_2 O_3$, $3 C_4 H_4 O_5$, or $Sb_2 (C_4 H_4 O_6)_3$. This salt, he says, is formed by dissolving antimonious oxide in tartaric acid, is easily soluble, crystallizes in four-sided prisms, and is deliquescent in the air. The remarkable statement is added that the formula is grounded only on the probable supposition that the salt must have this composition, but that it had not been analyzed. The second salt is described as follows: When alcohol is added to solutions of the first salt, a white granular precipitate is formed, which has the composition of "1 At. Antimonoxyd" and "1 At. Tartrylsäure"; that is, $Sb_2 O_3$, $C_4 H_4 O_5$. This salt, he says, loses one molecule of water of crystallization at 100°, and one molecule of water of constitution at 190°, becoming $Sb_2 O_3$, $C_4 H_2 O_4$. It is insoluble in water, but forms many double salts.

A paper by M. Eug. Péligot on "La composition des sels d'antimoine,"* read before the Académie des Sciences, Oct. 12, 1846, describes a crystalline and a precipitated tartrate of antimony. The former, he says, is formed after a long time in a sirupy solution of the tartrate of antimony obtained by dissolving the oxide in tartaric acid; the salt crystallizes in right rectangular prisms, is very soluble in water, and deliquescent in moist air. The formula assigned is equivalent to $Sb_2 C_{16} H_{32} O_{31}$. To represent the radical of tartaric acid, as now understood, this may be written $Sb (C_4 H_5 O_6)_2 OH \cdot 2\frac{1}{2} H_2O$. Péligot's numbers are given in the following table; but as he used a multiple of the old Berzelian atomic weight for antimony, 129·04, the theoretical percentages are recalculated with Sb=120.

	Found.		Theory, Péligot.	Theory, Sb=120.
Carbon	18·9 [1]	19·0 [2]	19·6	20·0
Hydrogen	3·5	3·5	3·2	3·3
Antimonious oxide	31·5	...	31·2	30·0
Water, $3\frac{1}{2}$ mol.	...	...	...	13·1
Loss at 160°	23·1 [3].			

[1] ·815 grm. salt gave ·566 CO_2 and ·263 H_2O.
·952 " " ·348 $Sb_2 S_3$.
[2] ·703 " " ·490 CO_2 and ·227 H_2O.
[3] 1·688 " lost ·343 H_2O at 160°.

* Reported in abstract in Compt. rend. **23**, 709 (1846); in full in Ann. chim. phys. [3] **20**, 289 (1847). A translation of the latter paper (with the same discrepancy in the numbers) is found in Jour. prak. Chem. **41**, 376 (1847).

The last figure in this table does not accord with the data in the foot-note, which would indicate a loss of only 20·32 at 160°; this discrepancy is probably due to a misprint of 1·688 for 1·488. This item is of little practical moment, for at the temperature selected the acid radical would probably undergo dehydration to an uncertain amount. It is quite probable that the water of crystallization exceeded 2½ mol.; while the low percentage of carbon with high percentage of antimony would indicate the probable admixture of some more basic salt.

Péligot's second salt was precipitated by alcohol from a concentrated solution of the first. This was analyzed (but only after drying at 160°), with the following very imperfect results. No antimony determination was published.

	Found.	Theory, for $Sb\,C_4\,H_3\,O_6$.
Carbon	16·4	17·2
Hydrogen	1·3	1·0

The formula equivalent to $Sb\,C_4\,H_3\,O_6$ thus assigned by Péligot may be derived from $Sb\,C_4\,H_5\,O_7$ by dehydration; and the analysis indicates the probability that such dehydration at 160° was partial only.

Berzelius and Péligot have thus each independently described two salts of similar preparation and properties; the formulas assigned may be expressed as follows, where T represents the bivalent acid radical $C_4\,H_4\,O_4$:

	Berzelius.	Péligot.
Crystalline	$Sb_2\,(O_2T)_3$	Sb (O–T–OH)$_2$ OH
Precipitated	$Sb_2\,(O_2T)\,O_2$	$Sb\,C_4\,H_3\,O_6$

In Watts' Dict. Chem. **5**, 683, three tartrates of antimony are described. The first is called "neutral antimonious tartrate," $(Sb\,O)_2\,C_4\,H_4\,O_6 \cdot H_2\,O$. This is the precipitated salt of Berzelius, with its water of crystallization, and the account given in Watts is taken directly from him, but is credited to Péligot. The second, a "hyperacid salt," is the crystalline salt of Péligot. To it is given the formula $(Sb\,O)_2\,C_4\,H_4\,O_6 \cdot 3\,C_4\,H_6\,O_6 \cdot 5$ aq., which may be written—

$$Sb \begin{cases} O—T—OH \\ O—T—OH + 2\tfrac{1}{2}\text{ aq.} \\ OH \end{cases}$$

This formula is given without the least shadow of a doubt upon its composition; while, in fact, as we have seen, Péligot's figures are not consistent with any formula. The third salt described in Watts is an "acid antimonious tartrate," the precipitated salt of Péligot; it is said that it has the formula $C_4\,H_5\,(Sb\,O)O_6$, that it is formed by the addition of alcohol to a concentrated solution of the hyperacid salt, and

that it gives off one molecule of water at 160°, leaving the salt $C_4 H_8 (Sb O) O_5$. These statements, which are attributed to Péligot, are largely based upon opinions of chemical analogy. Moreover, Professor F. W. Clarke and Miss Helena Stallo prepared in the laboratory of the University of Cincinnati a compound having the formula $C_4 H_5 Sb O_7$*, whose unstable properties show that it is very different from Péligot's precipitate.

In view of these facts the subject needs a thorough revision. Statements utterly devoid of proof have been copied and re-copied, with nothing to indicate their doubtful character. My own investigation was to settle the composition of these salts, and to show how they could be formulated rationally, as derived from trivalent antimony, without the intervention of the univalent basic group Sb O.

II.—EXPERIMENTAL INVESTIGATION.

Throughout this work I have estimated the antimony by precipitating a hot, slightly acid, aqueous solution of the salts with a stream of hydrogen sulphide in excess; carbon dioxide was then passed through to make the precipitate more granular and more easy to wash. The antimony sulphide was collected on a weighed filter and dried at 90°–100°. The error arising from free sulphur in the precipitate was eliminated by heating a weighed portion of it in an atmosphere of carbon dioxide. This method of estimating the antimony has many advantages and disadvantages; the use of a weighed filter is involved, and seven weighings are necessary, viz.: two for the salt, two for the weighed filter, two for a porcelain boat before heating in carbon dioxide, and one after heating. These disadvantages, together with the slow drying of the precipitate, make the estimation long and introduce experimental errors. The carbon and hydrogen were estimated as usual by combustion with copper oxide.

1.—*The Precipitated Salts.*

Though both Berzelius and Péligot describe a single precipitated salt, I have found that there are at least three simple tartrates of antimony which may be obtained by precipitating as many solutions of antimony in tartaric acid, each containing a different quantity of the metal.

Salt No. 1.—This salt was obtained in the form of a white, curdy precipitate on adding alcohol to a solution of antimonious oxide in a considerable excess of tartaric acid. The precipitate was washed with alcohol and dried over sulphuric acid to a white amorphous mass. It was easily soluble in water and slightly so in alcohol. I found it impossible to dry

* Amer. Chem. Jour. 2, 319, (1880).

the salt, even at 100°, as it melted to a thick gum. I have found it advisable in working with these salts to redissolve them in water and reprecipitate with alcohol; the salt comes down in coarser grains and dries more rapidly, with a less tendency to gum.

Analysis leads to the formula $Sb_2(O_2T)_3 \cdot 6H_2O$, where $T = C_4H_4O_4$, as follows:

	Found.	Theory.
Antimony	30·66 (mean) [1]	30·30
Carbon	18·14 [2]	18·18
Hydrogen (total)	3·01	3·03
Water lost at 155°–160°.	13·86 [3]	13·63

[1] ·3180 grm. salt gave ·1325 Sb_2S_3, or 29·76 % Sb.
·3725 " " ·1595 " " 30·58 "
·4441 " " ·1913 " " 30·76 "
·3633 " " ·1604 " " 31·54 "
[2] ·9233 " " ·6144 CO_2 and ·2503 H_2O.
[3] ·3486 " lost ·0483 H_2O at 155°–160°C.

Salt No. 2.—This salt was formed when alcohol was added to a solution of antimonious oxide in tartaric acid, obtained by boiling tartaric acid with an excess of the oxide. The white granular precipitate was filtered off, allowed to dry over night in the air, then redissolved in water and reprecipitated with alcohol. It dried over sulphuric acid to a white amorphous mass. The salt resembled in appearance the one just described; it dissolved easily in water, slightly in alcohol, and when it was collected it was supposed to be the same. Analysis agrees with the formula $Sb_2(O_2T)_2O \cdot 6H_2O$, as follows:

	Found.	Theory.
Antimony	36·55 (mean) [1]	36·36
Carbon	13·73 " [2]	14·54
Hydrogen	2·68 "	3·03
Water lost at 155°	16·32 [3]	16·36

[1] ·3441 grm. salt gave ·1777 Sb^2S^3, or 36·88 % Sb
·2350 " " ·1190 " " 36·23 "
·2677 " " ·1371 " " 36.55 "
[2] ·5621 " " ·2796 CO_2 or 13·56 % C, and ·1344 H_2O or 2·65 % H.
·7759 " " ·3955 " " 13·90 " " ·1896 " " 2·72 "
[3] ·2525 " lost ·0412 H_2O at 155°.

A portion of this salt was dissolved in water, and the solution allowed to evaporate spontaneously; it did not crystallize but dried into what the druggists know as a scale preparation—a clear, transparent, amber-

colored solid. This salt gave 16·39 per cent. of water (·7913 grm. of salt lost ·1297 H_2O at 165°), thus proving it to be the same hydrate as the original salt.

I was somewhat disappointed in this salt; for, when I found that it was not the same as the first one, I hoped that it might be the precipitated salt of Berzelius, to which he gives the formula $Sb_2 (O_2 T) O_2$, and which he says is insoluble in water.

Salt No. 3.—I determined to make one more attempt to obtain the salt of Berzelius; a quantity of tartar emetic was accordingly treated with dilute nitric acid, the precipitate was washed with water until the washings gave no reaction for nitric acid, and then boiled with fifty grammes of tartaric acid. The ratio of antimony to tartaric in the solution was about 4:5. There was an apparent excess of the antimonious oxide, for it would not dissolve entirely. The solution was precipitated with alcohol, the precipitate collected, washed with alcohol, and then redissolved in water and reprecipitated with alcohol. On being dried over sulphuric acid, it was more transparent than either of the other salts, and was all but insoluble in water. The analytical results approximate to the formula $Sb_2 (O_2 T)O_2 \cdot 2 H_2 O$, as follows:

	Found.	Theory.
Antimony....................	53·73 (mean) [1]	52·63
Carbon	5·90 " [2]	10·52
Hydrogen....................	1·57 "	1·75
Water lost at 140°..........	7·79[3]	7·89

[1] ·4539 grm. salt gave ·3407 $Sb_2 S_3$, or 53·62 % Sb
·3809 " " ·2872 " " 53·84 "

[2] ·5621 " lost ·1325 CO_2 or 6·43 % C, and ·0833 H_2O or 1·65 % H.
·5363 " " ·1059 " " 5·38 " " ·0732 " " 1·51 "

[3] ·7422 " " ·0578 H_2O at 140°.

The greatest difference between the theoretical and experimental percentages is in the carbon, which may have been due to an imperfect combustion, or to an admixture of $Sb_2 (OH)_8$ or basic salt.

This full series of tartrates precipitated by alcohol may now be compared in their graphical formulas with that for antimonious oxide; no evidence is found of the univalent radical, Sb=O, in place of hydrogen in tartaric acid.

Salt No. 1.........	T=O_2=Sb—O—T—O—Sb=O_2=T	+ 6 H_2O
Salt No. 2.........	T=O_2=Sb——O——Sb=O_2=T	+ 6 H_2O
Salt No. 3.........	T=O_2=Sb——O——Sb=O	+ 2 H_2O
Oxide..............	O =Sb——O——Sb=O	

In closing the discussion of the precipitated salts, I can only express my regrets that lack of time compelled me to give up this work before I had proved beyond a doubt the existence of $Sb_2 (O_2T) O_2 + aq$.

2.—*The Crystalline Salts.*

Both Berzelius and Péligot state that when a sirupy solution of antimonious oxide in tartaric acid is allowed to stand for some time, a salt crystallizes out in right rectangular prisms. All the crystals which I have obtained from such solutions, whether the evaporation was spontaneous or over a water bath, have been rosettes of needles.

The crystalline product is not constant, but the antimony in it decreases as the tartaric acid is increased in the mother liquor; and if sufficient antimony be present, the solution will not crystallize at all, but dries up into a solid transparent gum. Those solutions which will crystallize are more viscous, the greater the amount of antimony that they contain. This viscosity of the mother liquor, together with the soluble character of the crystals, is an almost insurmountable obstacle in the analysis of these salts. It is all but impossible to free the crystals of a mother liquor which is so thick that the vessel may be inverted without spilling. With this condition of affairs, one can not be sure that he is dealing with a pure product, even after several recrystallizations. Another difficulty is met with in drying the crystals, especially those rich in antimony; for when placed over sulphuric acid they effloresce on the outside, while they remain soft and sticky inside.

Owing to the varying percentages of antimony in the crystals which were found in preliminary experiments, I was led to make a series of solutions containing different amounts of antimony, as follows:

A.—40 grams of $Sb_2 O_3$ were boiled with an aqueous solution of 60 grms. of tartaric acid for 24 hours. The solution was incomplete. The filtered solution was evaporated to dryness. The product will be described below. Sb=27·53 per cent.

B.—35 grams of $Sb_2 O_3$ were boiled with 60 grams of tartaric acid for 24 hours. This solution was still incomplete. It yielded crystals which could not be purified for analysis on account of the viscosity of the mother liquor.

C.—30 grams of $Sb_2 O_3$ were boiled with 60 grams of tartaric acid. The solution was complete. The crystals were washed and recrystallized twice.

D.—20 grams of $Sb_2 O_3$ were dissolved in 60 grams of tartaric acid.

The solution was complete and the product recrystallized. Several distinct lots of crystals were prepared at different times. The last product (**De**) was dried with extreme care and analyzed. The results are given below.

E.—15 grams of $Sb_2 O_3$ were dissolved in 60 grams of tartaric acid. The product was twice recrystallized. The crystals, which were less sticky than when a larger amount of the oxide was used, yielded 5·37 per cent. Sb, and was probably a mixture containing free tartaric acid.

F.—12 grams of $Sb_2 O_3$ were dissolved in 60 grams of tartaric acid. Product recrystallized. The product, though recrystallized, was a mixture.

The analytical data and results for the determinations of antimony are given in the following table:

A.	·4773	gram	salt	gave	·1840	$Sb_2 S_3$	or	27·53%	Sb.
C.	·7587	"	"	"	·2010	"	"	18·92	"
Da.	·3751	"	"	"	·0701	"	"	13·35	"
Db.	·9668	"	"	"	·2153	"	"	15·90	"
Dc.	·8570	"	"	"	·1978	"	"	16·48	"
	1·0633	"	"	"	·2478	"	"	16·64	"
Dd.	·4979	"	"	"	·1114	"	"	16·18	"
	·7172	"	"	"	·1617	"	"	16·21	"
	·5554	"	"	"	·1334	"	"	17·16	"
De.	1·5341	"	"	"	·3847	"	"	17·88	"
	1·0843	"	"	"	·2733	"	"	18·00	"
E.	·5543	"	"	"	·0417	"	"	5·37	"
F.	·8839	"	"	"	·0443	"	"	3·69	"
	·4583	"	"	"	·0245	"	"	3·82	"

Salt No. 4.—The crystals **C** and **De** of the foregoing list had all the characteristics of definite compounds and proved to be $Sb\,(O\text{–}T\text{–}OH)_3 \cdot 4\,H_2O$, as the analysis will show.

	Found.			Theory.
	C	**De**		
Antimony	18·92 [1]	17·88 [1]	18·00 [1]	18·78
Carbon	22·59 [2]	22·98 [3]		22·53
Hydrogen	3·78	3·39		3·60
Water lost at 120°..	11·05 [4]	10·98 [5]		11·27

[1] See the table above.

[2] ·7201 gram salt gave ·5965 CO_2 and ·2449 H_2O.

[3] ·7945 " " " ·6727 " " ·2421 "

[4] ·9534 " " lost ·1054 H_2O at 120°.

[5] ·7218 " " " ·0793 " " "

This body, which may be called antimonio-tritartaric acid, is very soluble in water, effervesces strongly with carbonates, and behaves like a weak acid. If alcohol be added to its solution, the salt $Sb_2\ (O_2\ T)_3 \cdot 6\ H_2O$, is precipitated.

Salt No. 5. —Solution **A** would not crystallize. A portion of its gummy solution was left upon the water-bath for 48 hours; upon cooling the tartrate was an amber-colored solid, which was ground up in an agate mortar to a straw-colored powder. This powder was analyzed, with the following results, and appeared to be $Sb\ (O\text{–}T\text{–}OH)_2\ OH$.

	Found.	Theory.
Antimony	27·53 [1]	27·58
Carbon	18·31 [2]	22·06
Hydrogen	2·96	2·53
Water lost at 105°	10·92 [3]	

[1] ·4773 gram salt gave ·1840 $Sb_2\ S_3$.
[2] ·7201 " " " ·4836 CO_2 and ·1923 H_2O.
[3] ·7802 " " lost ·0852 H_2O at 105°.

The water estimation behaved in a very peculiar manner; for, though the salt was at no time heated higher than 105°, it lost in weight gradually for more than a day and a half. The percentage loss at successive weighings was as follows:

5·79, 6·85, 7·67, 8·15, 8·67, 9·02, 9·27, 10·21, 10·70, 10·92.

I am inclined to think that this loss in weight was due to a decomposition of the salt, for when alcohol was added to its solution, the precipitate had the composition of the precipitated salt No. 2, $Sb_2\ (O_2\ T)_2\ O \cdot 6\ H_2O$.

Summary.—On comparison of the crystalline or acid salts with the precipitated or neutral salts, we have two series of tartrates, one derived from the antimony hydrate or the antimonious acid, $Sb\ (OH)_3$; the other from antimonious oxide $Sb_2\ O_3$. Thus, neglecting the water of crystallization, we may write:

$$\begin{array}{cccc} 1 & 2 & 3 & \text{Oxide.} \\ \begin{array}{l} \mathrm{Sb}\{=O_2=T \\ \quad\ \ =O_2=T \\ \mathrm{Sb}\{=O_2=T \end{array} & \begin{array}{l} \mathrm{Sb}\{=O_2=T \\ \quad\ \ =O \\ \mathrm{Sb}\{=O_2=T \end{array} & \begin{array}{l} \mathrm{Sb}\{=O_2=T \\ \quad\ \ =O \\ \mathrm{Sb}\{=O \end{array} & \begin{array}{l} \mathrm{Sb}\{=O \\ \quad\ \ =O \\ \mathrm{Sb}\{=O \end{array} \end{array}$$

$$\begin{array}{cccc} 4 & 5 & 6 & \text{Hydrate.} \\ \mathrm{Sb}\left\{\begin{array}{l} O\text{—}T\text{—}OH \\ O\text{—}T\text{—}OH \\ O\text{—}T\text{—}OH \end{array}\right. & \mathrm{Sb}\left\{\begin{array}{l} O\text{—}T\text{—}OH \\ O\text{—}T\text{—}OH \\ OH \end{array}\right. & \mathrm{Sb}\left\{\begin{array}{l} O\text{—}T\text{—}OH \\ OH \\ OH \end{array}\right. & \mathrm{Sb}\left\{\begin{array}{l} OH \\ OH \\ OH \end{array}\right. \end{array}$$

It has been suggested to me by Prof. F. W. Clarke to call the tartrates derived from antimonious oxide, Nos. 1, 2, and 3, antimony tri-, di- and

monotartrate, respectively, and those derived from the hydrate, Nos. 4, 5, and 6, antimonio- tri-, di- and monotartaric acid respectively.

Of these I have obtained conclusively, as is shown in my figures, No. 1, the antimony tritartrate and its corresponding acid, No. 4. No. 2 was evidently formed, but No. 5, the antimonio-ditartaric acid, was obtained in rather a hypothetical manner. Great difficulty was experienced in even approximating to No. 3, the antimony monotartrate, while No. 6 was not obtained at all.

3.—*Double Salts and Other Derivations.*

From Antimonio-Tritataric Acid.—When barium carbonate is treated with antimonio-tritartaric acid, there is a brisk effervescence and the barium goes into solution, but on standing crystals of the ordinary barium tartrate are deposited. In another experiment the antimonio-tritartaric acid was neutralized with barium carbonate, and alcohol added to the filtered solution; a copious, white, granular precipitate was formed. After this was dried at the temperature of the air over sulphuric acid, it was partially insoluble in water, and gave the following percentages on analysis, approximately agreeing with $Sb_2(O_2T)_3 \cdot 4\ Ba\ (O_2T) \cdot 3\ H_2O$.

	Found.	Theory.
Antimony............	12·47 [1]	12·77
Barium	28·27 [2]	29·17
Water lost at 150°..	2·45 [3]	2·87

[1] ·4071 gram salt gave ·0711 Sb_2S_3.
[2] " " " " ·1958 $Ba\,SO_4$.
[3] ·3305 " " lost ·0071 H_2O at 150°.

It is doubtful whether this is a definite compound.

From Antimonio-Ditartaric Acid.—This compound behaved in every respect like the tritartaric acid. It was strongly acid, effervesced with carbonates, and was not precipitated by alkalies in the cold. Its solutions, when neutralized with barium carbonate and precipitated by alcohol, yielded a white curdy precipitate, which was dried over sulphuric acid. It did not dissolve entirely in water. A partial analysis agrees with the formula $Sb_2(O_2T)_2O \cdot 3\ Ba\ O_2T \cdot 11\ H_2O$:

	Found.	Theory.
Antimony..................	15·33	14·94
Barium......................	26·06	25·58
Water lost at 150°.......	12·66	12·32

[1] ·3801 grm. salt gave ·0818 Sb_2S_3
[2] ·3801 " " ·1685 $Ba\,S\,O_4$
[3] ·4027 " lost ·0510 H_2O at 150°.

This is probably a mixture; though it (as well as the corresponding salt of the antimonio-tritartaric acid) may be weak double compounds.

A portion of the antimonio-ditartaric acid was neutralized with sodium carbonate; the liquid, which remained clear, was then mixed with alcohol. It immediately had the appearance of an emulsion, but later separated into two layers, both of which were clear, the lower one being decidedly yellow, and both contained antimony. The lower layer was sirupy and contained most of the sodium; it was accordingly drawn off by means of a separatory funnel. It evaporated at the temperature of the air over sulphuric acid to an amber-colored solid, which yielded a light yellow powder. Although a definite compound was hardly to be expected, the results of an analysis agree fairly well with the formula $2\ Sb\ (OH)_3 \cdot 3\ Na_2 O_2T \cdot 3\ H_2O$. This salt was soluble in water and turned blue litmus paper faintly red. Its aqueous solution was not decomposed on boiling, but was precipitated by alkaline carbonates.

	Found.		Theory.
Antimony	24·66[1]	25·00[2]	24·54
Sodium	13·48[3]		14·11
Carbon	15·77[4]	15·64[5]	14·72
Hydrogen	2·62		2·45
Water lost at 150°	11·66[6]		11·04

[1] 1·0131 grm. salt gave ·3497 Sb_2O_3
[2] ·5290 " " ·1852 "
[3] 1·0131 " " ·4217 Na_2SO_4
[4] ·7091 " " ·4102 CO_2 and ·1673 H_2O
[5] 1·0844 " " ·6221 CO_2
[6] ·9493 " lost ·1107 H_2O at 150°.

Another portion of the antimonio-ditartaric acid solution was exactly neutralized with sodium carbonate; the fluid remained clear, but upon boiling deposited a heavy slimy precipitate, which was filtered off and placed over sulphuric acid, when it dried with extreme slowness to a light yellow solid, which was very insoluble in water. The filtrate from this precipitate, which was neutral, was treated with an excess of sodium carbonate, and the fluid boiled; a second precipitate was white and granular. This was also dried over sulphuric acid and was insoluble in water. Neither of the precipitates contained any sodium.

Both precipitates were analyzed. The first gave results which approximate to the formula $Sb_4O_5(O_2T) \cdot 12\ H_2O$, analogous to the sulphate $Sb_4O_5(SO_4)$ the chloride $Sb_4O_5(Cl)_2$, etc.

	Found.		Theory.
Antimony..................	47·87[1]	47·28[2]	51·95
Carbon......................	3·96[3]	4·24[4]	5·20
Hydrogen..................	3·44	3·21	3·03
Water lost at 155°.......	22·30[5]		23·37

1 ·4652 grm. salt gave ·3118 $Sb_2 S_3$
2 ·4543 " " ·3007 "
3 ·6619 " " ·0962 CO_2 and ·2051 H_2O
4 ·9316 " " ·1449 CO_2 and ·2695
5 ·9102 " lost ·2030 H_2O at 155°.

The second precipitate was evidently antimonious oxide mixed with a little hydrate., Its analysis gave the following percentages:

	Found.	Theory.
Antimony..................	84·25[1]	83·33
Water lost at 150°........	4·80[2]	

1 ·7643 grm salt gave ·7297 Sb_2O_4
2 ·7643 " lost ·0372 H_2O at 150°.

These results indicate the probability of a basic antimony tartrate, formed by the precipitation of the higher tartrates, as a step in the reduction of those higher tartrates to the oxide.

Antimony disulphato-tartrate?—A cold solution of antimony ditartrate, $Sb_2 (O_2T)_2O \cdot 6 H_2O$, was cautiously mixed with cold dilute sulphuric acid until it was faintly turbid, and then alcohol was quickly added. The white precipitate which formed was collected and dried over sulphuric acid; it contained antimony, sulphuric and tartaric acids, and water. It was insoluble in water. A partial analysis gave results which agree best with the formula $Sb_2 (O_2T) (SO_4)_2 \cdot 7 H_2O$. The results were:

	Found.		Theory.
Antimony..................	33·56[1]		33·99
SO_4..........................	25·48[2]	25·52[3]	27·19
Water lost at 110°........	12·31[4]		17·84

1 ·3192 grm. salt gave ·1500 $Sb_2 S_3$
2 " " " ·1974 $Ba SO_4$
3 ·3684 " " ·2282 "
4 ·3192 " lost ·0393 H_2O at 110°.

The antimony and sulphuric acids found are both decidedly low. The product may easily have been mixed with $Sb_2 (O_2T)_2 SO_4 +$ aq. and $Sb_2 (O_2T) (SO_4) O +$ aq. The fuller study of such derivatives is still open for investigation.

Tartrates of Silver and Antimony.—One or two double salts containing silver, antimony, and tartaric acid, were prepared in the following manner: An excess of silver tartar-emetic was dissolved in a comparatively

large amount of water; amyl iodide was then added; the yellow silver iodide was immediately precipitated, while the excess of silver tartar-emetic remained in solution. The silver iodide was then filtered off, and the solution evaporated by boiling, until small crystals appeared upon the surface of the liquid; upon cooling, a large number of clear, small pyramidal crystals, which were almost insoluble in water, adhered to the bottom and sides of the vessel. An analysis of these crystals agrees best with the formula $Ag_2\ Sb_4\ (O_2T)_3\ O_4 \cdot 3\ H_2O$. The results were:

	Found.		Theory.
Antimony..................	37·37[1]	38·54[2]	38·15
Silver........................	17·19[1]		17·17
Carbon.......................	11·21[3]	11·26[4]	11·45
Hydrogen..................	1·15[3]	1·21[4]	1·42
Water lost at 150°......	3·43[5]		4·29

[1] ·2202 grm. salt gave ·0503 Ag Cl.
" " " ·1152 $Sb_2\ S_3$.
[2] ·6761 " " ·3648 "
[3] ·5144 " " ·2116 CO_2 and ·0532 $H_2\ O$.
[4] ·4533 " " ·1908 " ·0494 "
[5] ·6761 " lost ·0232 gr. water at 150°.

The formula of this salt may be written a variety of ways; the following (omitting the water) is symmetrical, with a fair distribution of electro-positive and electro-negative elements throughout the chain, but there is no proof of its symmetry or of the two closed rings.

$$Ag{-}O{-}T{-}O{-}Sb{=}O_2{=}Sb{-}O{-}T{-}O{-}Sb{=}O_2{=}Sb{-}O{-}T{-}O{-}Ag.$$

Several peculiar facts presented themselves in making the water estimation; the salt at 125° had lost 2·51 per cent. of water, and had turned the color of red lead; at 150° the loss was 3·43 per cent., and the salt had become very green and quite specular.

The preparation of the second salt was exactly similar to that of the one just described, except that ethyl iodide was substituted for the amyl iodide. The crystals resembled those of the first salt to a marked degree, but adhered more closely to the surface of the crystallizing dish. It was also insoluble in water. An analysis gave results which agree best with the formula $Ag_3\ Sb_4\ (O_2T)_3\ HO_5 \cdot 3\ H_2O$. The results were:

	Found.	Theory.
Antimony..................	$\left.\begin{matrix}33·37\\21·61\end{matrix}\right\}$ [1]	34·70
Silver........................		23·42
Carbon.......................	$\left.\begin{matrix}11·86\\1·16\end{matrix}\right\}$ [2]	10·48
Hydrogen..................		1·37
Water lost at 150°........	4·44[3]	3·90

1 ·2838 grm. salt gave ·0815 Ag Cl and ·1326 Sb_2S_3.
2 ·5287 " " ·2301 CO_2 and ·0552 H_2O.
3 ·5611 " lost ·0258 water at 150°.

The graphical formula need not differ from the last, except in breaking one of the rings to attach Ag and OH,

```
                 H       Ag
                 |       |
                 O       O
                 |       |
Ag—O—T—O—Sb—O—Sb—O—T—O—Sb=O₂=Sb—O—T—O—Ag.
```

This salt possessed the same physical properties as the first one, even to the change of colors in the water estimation. Neither of these salts, in treating with caustic potash, yielded any alcohol corresponding to the iodide which was used. The apparent difference of composition may be due to some admixture.

*Aniline Tartar Emetic.**—This salt was prepared by heating a solution of the barium tartar-emetic with aniline sulphate, and filtering to free the solution of barium sulphate. On standing over night, long, flattened, rectangular prisms separated out, the largest of which was about four centimeters. The first crop of crystals was dark purple, but on two re-crystallizatious they became nearly white; the gradations in color between the dark purple and pinkish white were very beautiful.

The salt is simply tartar-emetic, with aniline substituted for the potassium, and is devoid of water of crystallization. Its formula is Sb (C_6 H_7 N·H) O_3T.

Antimony gave the following percentages:

	Found.	Theory.
Antimony....................	31·73 (mean)	31·74

·6101 grm. salt gave ·2574 Sb_2 S_3, or 30·38 % Sb
·8566 " " ·3911 " " 32·60 "
·4028 " " ·1817 " " 32·22 "

It should be stated, in conclusion, that in all the salts described above, antimony behaves as an ordinary trivalent metal. This may, therefore, be considered its normal condition in the simple tartrates and their analogues.

I can not close this paper without expressing my thanks to Professor F. W. Clarke for his constant aid and advice during a task of several months.

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* An account of this salt (with its specific gravity, 1·890) was published in Ber. d. chem. Gesel. **15**, 1540 (1882).

NOTE ON STRUCTURAL FORMULÆ OF TARTRATES OF ANTIMONY.

BY ROBT. B. WARDER.

While the preceding paper was in type, the "Researches on the Tartrates of Antimony," by Clarke and Evans, appeared in Amer. Chem. Jour. **5**, 241 (Sep. 1883).

The conclusions reached by Mr. Evans, as published above, admit of two interpretations. Peligot's suggestion of the univalent radical, —Sb=O, has been generally accepted without a question, but Professor Clarke and Miss Stallo proposed a different theory a few years ago;* both views may be thus illustrated in tartar emetic, when the formulæ are expanded:

$$K\text{–}O\text{–}CO\text{–}C_2H_2(OH)_2\text{–}CO\text{–}O\text{–}Sb{=}O \quad \text{(Peligot)}$$
$$C_2H_2(OH)_2\text{–}(CO\text{–}O)_2{=}Sb\text{–}O\text{–}K \quad \text{(Clarke).}$$

According to Peligot, $C_4H_4O_4$ alone acts as an acid radical, while Sb=O simply replaces the hydrogen of carboxyl. According to Clarke's formula, on the other hand, Sb has a double character, replacing hydrogen, both in carboxyl of tartaric acid and in potassium hydrate, linking together a metal and an acid radical. It is hardly needful to point out the *a priori* improbability of such an arrangement, upon the electrochemical theory; for this formula seems to be withdrawn in the recent paper by Clarke and Evans, who now prefer to double Peligot's formula, thus:

$$K\text{–}O\text{–}T\text{–}O\text{–}Sb{=}O_2{=}Sb\text{–}O\text{–}T\text{–}O\text{–}K.\dagger$$

For Kessler's double salt of strontium tartar emetic and strontium nitrate,‡ they propose a formula equivalent to

$$NO_2\text{–}O\text{–}Sr\text{–}O\text{–}T\text{–}O\text{–}Sb{=}O_2{=}Sb\text{–}O\text{–}T\text{–}O\text{–}Sr\text{–}O\text{–}NO_2$$

but this is more simply explained by writing

$$NO_2\text{–}O\text{–}Sr\text{–}O\text{–}T\text{–}O\text{–}Sb{=}O,$$

which is combined with 6 H_2O, and, therefore, does not require to be doubled.

In conclusion, Peligot's hypothesis of a univalent radical, SbO, presupposes antimony "as an ordinary trivalent metal;" it is not antagonistic

* Ber. d. chem. Gesel. **13**, 1787 (1880) and Amer. Chem. Jour. **2**, 319, (1880).

† Loc. cit., p. 249. Compare also the formulæ suggested by Clarke in these PROCEEDINGS, **1**, 51.

‡ Pogg. Ann. **75**, 410 and Jour. prak. Chem. **45**, 361 (1848).

to the existence of "perfectly normal tartrates;" its occurrence is clearly proved in Sb_2O_3 and many other compounds; and no valid objection has been urged against its existence in tartar emetic or its derivatives.

XII.—DEVELOPMENTS IN THE KINETIC THEORY OF SOLIDS, LIQUIDS, AND GASES.

By H. T. EDDY, C. E., PH. D., University of Cincinnati.

[Concluded from page 97.]

PART III.—ON THE KINETIC THEORY OF THE SPECIFIC HEAT OF SOLIDS.

IN the second part of this paper, entitled *Kinetic Considerations as to the Nature of the Atomic Motions which probably originate Radiations* (pages 89–97), the author has given reasons in support of the hypothesis that the atoms of the different chemical elements are all composed of the same kind of ultimate atoms, which are in every respect equal and similar. Reasons were also given, tending to show that the vibrations of these ultimate atoms originate luminiferous and thermal radiations. And, further, an attempt was made to prove—in case radiations are due to vibrations of equal and similar ultimate atoms, which are set in vibration by the collisions of moving molecules—that two unlike masses of gas, which are in thermal equilibrium by radiation, will also be so when they are mixed; *i. e.*, when the equilibrium depends upon the collisions of molecules rather than upon radiation.

The object of the present paper is to consider the probable physical state of solid bodies, especially as to the amount of energy distributed among the different degrees of freedom possible in such bodies; and to show that the same hypothesis—of equal ultimate atoms—would cause solids, which are in equilibrium by radiation, to be also in thermal equilibrium when brought into contact; *i. e*, when the equilibrium depends upon the collisions of the molecules.

In the first place, let us notice what is apparently the mechanical significance of Dulong and Petit's law, which may be stated thus: The amount of heat which must be imparted to a chemical atom of a simple solid body to raise its temperature one degree is approximately the same for all the elements. Neumann has further shown that for compound solids, those of similar chemical composition require approximately the same amount of heat per chemical atom, but the amount is less than for

simple solids. There are, however, a few unexplained exceptions to these laws, which are due, possibly, to uncertainty as to atomic weights. The mechanical explanation of these experimental laws seems to be contained in the statement that in simple solids cohesion and chemism are one and undistinguishable; or, to express it otherwise, we may say that the molecules of simple solids are monatomic, the cohesion being of course much greater in some solids than in others. That this is a correct conception of the relations of the atoms of simple solids is made probable by various facts; among these it may be mentioned that mercury and cadmium, which are known to be monatomic as gases, as solids fulfill Dulong and Petit's law, and are therefore in the same physico-chemical condition as other simple solids.

Another fact is that already mentioned, to-wit, that the specific heat of atoms of compound solids is less than that of simple solids; and to this it may be added that the specific heat of simple solids is less when the volume is made smaller by hammering, compression, or cooling—which facts will be considered more at length later.

It is shown in the kinetic theory of gases, that when molecules of unlike gases are mixed together, the mean progressive energy of each molecule is the same, whatever its weight. Now, when a gas is in contact with a solid, will the collisions of the gaseous molecules with those of the solid cause the latter to have the same mean progressive energy of vibration as those of the gas? That will depend largely upon the duration of the collision. If the time occupied by a collision is so brief that only a small portion of a vibration of a solid molecule is described during the collision, then the laws of impulsive forces may be applied, according to which the effect of the finite forces, acting during the interval, may be neglected. In case the collision is brief, the distribution of the mean kinetic energy between the molecules of the gas and the solid will be very nearly the same as between different gases, and the mean kinetic energy of a simple solid molecule will differ little from that of a gas at the same temperature.

In cases, however, in which the modulus of elasticity of the solids considered is so great as to make the period of vibration of the molecules also brief, their mean kinetic energy would be materially smaller than in the previous case; and, if a solid could be found whose molecules were immovably fixed, no vibratory energy could be imparted to its molecules.

Now Dulong and Petit's law seems to show that all simple solids, even those having the highest modulus of elasticity, have an elasticity so small compared with that brought into action between molecules at the instant

of free collision, that the distribution of kinetic energy is approximately the same as if the body were gaseous and monatomic.

But since the laws of perfect elasticity require that the mean potential energy shall be equal to the kinetic, it follows that the specific heat of a simple solid should be approximately twice that of a monatomic gas at the same temperature and of the same atomic weight. The actual specific heats of mercury and cadmium gas would be of interest in this connection were they known, even though they could only be determined at temperatures far removed from those of their solids.

The foregoing statement has been based upon the assumption that any degree of freedom which suffers partial constraint, as do the degrees of freedom of translation of a gaseous molecule when it becomes solid, will have for that reason less kinetic energy imparted to it during molecular collision. This matter has been treated somewhat at length in previous papers upon the virial, but in this connection it may be useful to make a quotation from Thomson and Tait:* "If a set of material points are struck independently by impulses each given in amount, more kinetic energy is generated if the points are perfectly free to move, each independently of all the others, than if they are connected in any way."

This mechanical theorem has special application not only to the partial constraints introduced into the freedom of motion of molecules, when they change from a gaseous to a solid state, but it applies also to the additional constraints introduced into the degrees of freedom of solid atoms when those atoms become more closely bound together by chemism into groups or molecules. Evidently the bonds of union between the atoms of a compound solid molecule are such that these degrees of freedom are considerably more constrained than those which unite the atoms of different molecules; so that in compound solids the forces of cohesion and chemism are different and quite distinguishable the one from the other. Now what, according to the mechanical theorem above quoted, is the effect of introducing the additional constraints required in order to group a simple solid, or a mixture of simple solids, into molecules, and thus make it a compound solid? The effect will be to diminish the mean kinetic energy of the system as derived from the impacts of the molecules of any gas surrounding it. This is in fact what occurs, as appears from the experimental truth previously mentioned, that the specific heat per atom of compound solids is less than that of simple solids. How much the specific heat per atom is diminished should depend upon the intensity

* Nat. Phil., Art. 315.

of the chemical attraction, which certainly must be much greater than the cohesion between atoms of simple solids to cause such marked deviations of specific heat per atom as compound solids exhibit.

This result, when combined with that arrived at in connection with the discussion of Berthelot's law, in my paper upon *An Extension of the Theorem of the Virial, etc.*,* to the effect that the heat evolved in chemical decomposition is greater the greater the attractive force, enables us to enunciate the following law, the truth of which I am at present unable to verify for want of sufficient experimental data: Those solids, other things being equal, which evolve the greater amount of heat of chemical decomposition in changing from simple mixtures to compound solids, are those which have less specific heat per atom. The phrase, "other things being equal," in the above statement refers to the fact that compounds alone that are chemically similar are in strictness comparable. Many other circumstances, moreover, besides want of chemical similarity, may in special cases mask the experimental results, yet the truth of the law should be clearly recognizable in any general comparison of specific heats with the heat of formation of compound solids.

Similar principles evidently apply to the cases in which simple solids are permanently decreased in volume by hammering or compression, for then greater cohesive forces are brought into action, and the specific heat is diminished.

It remains to be shown, in conclusion, that thermal equilibrium, which has been established by collisions of gaseous and solid molecules, will continue to exist when its continuance depends upon radiations between equal and similar ultimate atoms, which are set in vibration by molecular collisions; or, to state it differently, it remains to be shown that the ultimate atoms of a gas and a solid in contact, each have the same mean vibratory energy with respect to each of their degrees of freedom, with respect to each other. This appears to be a direct consequence of the principles of constrained motion which have been considered in this and previous papers. It is only necessary that the impacts of a pair of solid molecules with each other should be such as to mutually impart and receive the same mean amounts of energy as those of a gas and a solid, to cause it to be a matter of indifference whether a given solid molecule is struck by another solid molecule or by a gaseous molecule, and when so struck each ultimate atom will receive its proper proportion of energy, whether it form part of a solid or of a gaseous molecule.

* These PROCEEDINGS, **2**, 26–43 (March, 1883).

It is my intention to return to this subject hereafter, and to treat the vibrations of ultimate atoms more at length, in the hope of being able to show more precisely than has been done so far how the characteristic differences in the spectra of solids and gases exist.

IV. Liquefaction, Vaporization, and the Kinetic Theory of Solids and Liquids.*

In a solid, in which the molecules are evidently held at nearly fixed mean distances by cohesive and elastic forces, there are two kinds of partially constrained freedom of motion possible for each molecule as a whole; first a motion of its center in a small orbit of more or less irregular shape about a mean position; and second, a more or less irregular pendular motion of oscillation about a mean directional position. Both of these motions can be properly treated as vibratory motions, and the laws of force, under which the motions occur, though somewhat unlike, as will appear during the following discussion, have a general resemblance.

When a solid is liquefied, it is evident that the molecules slide on each other with facility, which is equivalent to supposing that the molecules of the body have become perfectly free as to directional position; and this may be explained by supposing that the pendular oscillation has been changed into rotation.

In order to give a clearer conception of how the mean potential and kinetic energies have been effected by such a change, let us consider the case of a simple pendulum, which may be taken to be a heavy particle suspended by a thin rigid rod. It is well known that for any small oscillation of this pendulum the mean potential and kinetic energies are equal, but for oscillations of more considerable amplitude this is far from being the case. In order to compare the mean potential and kinetic energies for larger amplitudes, it will be useful first, to make comparison in case of a body of unit mass falling freely through a height s under the action of gravity, in which case we must, in order to obtain the mean kinetic energy, compute the mean value of $\frac{1}{2}v^2 = gs$ during the fall. Let the mean value be denoted by a horizontal stroke

$$\therefore \tfrac{1}{2}\overline{v^2} = \overline{gs} = \frac{g\int s\,dt}{\int dt} \qquad (1)$$

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*This part was published in Frank. Inst. Jour. [3] **86**, 8–17 (July, 1883).

Since by the laws of falling bodies

$$s = \tfrac{1}{2} g t^2 \tag{2}$$

$$\therefore\ \tfrac{1}{2}\overline{v^2} = \tfrac{1}{6} g^2 t^2. \tag{3}$$

But the total energy, potential and kinetic, which is evidently constant during the fall, is by (2),

$$gs = \tfrac{1}{2} g^2 t^2, \tag{4}$$

and this is, therefore, also the mean value of the total energy. We obtain the mean value of the potential energy by taking the difference of the means.

$$\therefore\ g\,(s - \bar{s}) = \tfrac{1}{3} g^2 t^2. \tag{5}$$

Hence by (3) the mean potential energy in a free fall is twice the mean kinetic energy. The same result holds in case of a body sliding down a smooth inclined plane. This result may then be applied to oscillations such as occur in the ideal case of a perfectly elastic particle which rebounds from a horizontal plane, whether vertically or obliquely, as is the case when it slides down one incline of a **V** and then ascends the other without friction. We are now in a position to see what is the relation between the potential and kinetic energies in case a smooth particle oscillates by sliding down one branch of a **U** and ascending the other. In the lower part of the curve the velocity is near its maximum value, and as this part of its path is more extended than before, the mean kinetic energy is greater in the **U** than in the **V**. Were the parts of the **U**, which are nearly vertical, put at a more considerable distance asunder, the mean kinetic energy could be increased at will by so doing. Now, it is known, in case the curve on which the particle oscillates is a cycloid, that the mean potential and kinetic energies are equal. Hence, in case it oscillates by sliding on any smooth curve, such as a semicircle, whose vertical branches are not so far asunder as those of the cycloid which has a height equal to the radius of the circle, the mean kinetic is less than the mean potential energy. And it further appears that while for small oscillations the mean kinetic and potential energies are approximately equal, that as the amplitude of the oscillation increases, the mean kinetic energy is a smaller and smaller fraction of the total energy and of the mean potential energy. The same holds true in case the amplitude of the oscillation of the circular pendulum is pushed beyond 90° on each side of the mean. In fact, in case the kinetic energy at its lowest point is just sufficient to carry the particle to the highest point of the circle, the particle will rest there in unstable equilibrium, in which case

the mean kinetic energy will vanish, since the time of oscillation is then infinite and the total energy will become potential and remain so. Thus we see that the mean kinetic energy of the pendulum may be any fraction of the total energy less than one-half, according to the amplitude of the oscillation.

But there is one other circumstance of importance in this kind of oscillation, which is, that, although its total energy is constantly increased as the amplitude increases, it is far otherwise with the mean kinetic energy. This at first increases with the amplitude, though not so rapidly as the mean potential energy, but as the amplitude approaches 180° the time of oscillation is so greatly increased that the mean kinetic is actually decreased by an increase of amplitude. There is, therefore, a certain amplitude at which the mean kinetic energy is a maximum. What that amplitude may be, it does not now concern us to determine; the only point necessary to consider is the one stated, that an increase of total energy and a consequent increase of amplitude will in no case increase the mean kinetic energy unless the amplitude of the oscillation be carried to more than 180°. As has been seen, a considerable increase of total energy will serve only to diminish the mean kinetic energy, but if sufficient total energy be supplied to the pendulum the amplitude will exceed 180° and its motion will be changed from that of oscillation to revolution, and on sufficiently increasing the total energy the mean kinetic energy of revolution will be equal to the mean maximum kinetic energy of oscillation.

The application of the foregoing discussion to the oscillatory motion of the molecules of solid bodies is obvious. In case a molecule has one or more positions of directional equilibrium about which it oscillates, a sufficient increase of total energy (*i. e.*, heat) will bring its mean kinetic energy of oscillation to a maximum, and in order further to increase its mean rotary kinetic energy a large amount of potential energy (*i. e.*, latent heat) must be supplied to change the oscillations into rotations of the same mean kinetic energy (*i. e.*, to melt the body).

There is one other point to be noticed in this connection, which is, that according to this theory the specific heat of a solid will in general increase as its temperature rises towards the melting-point, which is in general accordance with experiment. It would be necessary, however, in order that this should universally be the case, to show that the mean energy of the particular molecular motion which is the physical cause of radiant heat, is proportional to the mean energy of the motion which we are now discussing. It is generally thought that such a relation exists,

and it is certainly highly probable that the ratio between them does not change rapidly with the temperature.

The results which we have here obtained are not due to the fact that the force causing the oscillation considered was a special function of the amplitude, or of the distance of the particle from its mean position. The only vital point is that the oscillation shall be such that there shall be a maximum value of the mean kinetic energy. This remark has special application to the phenomenon of vaporization also, which we shall now consider. In vaporization the molecules are evidently removed to such considerable mean distances from each other that their paths are mostly free from mutual interference, while, before vaporization, the molecules are in no part of their paths free from mutual action and reaction.

In considering the forces which act along a line joining two molecules between which cohesive forces act, the phenomena of cohesion and of resistance to compression make it evident that the force with which a molecule is drawn towards its mean position, when their mutual distance is slightly greater than the mean, is one which at first increases with the displacement of the molecule from its mean position, but the displacement can not be large without carrying the molecules beyond the range of their mutual cohesion. If, however, their mutual distance be decreased, the force tending to restore a molecule to its mean position increases with the displacement, and in such a manner that no force can bring them into actual contact.

The cohesive force actually existing between the molecules of a liquid is so masked by the phenomena necessarily accompanying liquidity that its true character has been largely overlooked. There is, however, no reason, as we think, to suppose that the forces acting to prevent decrease of volume in a fluid are different initially from those resisting dilatation, or at least that they differ more than the same forces do in a solid body.

In order that we may make clear the relations between potential, kinetic and total energy in case of vibration under the action of molecular forces of this character, we shall in the first place discuss the subject of the relation between the law of force and the distribution of potential and kinetic energy somewhat in detail. The law of force in case of the pendulum already discussed is

$$y = \sin x \qquad (6)$$

in which y is proportional to the force acting to restore the particle to its mean position, and x is proportional to the displacement of the particle from its mean position at the origin measured along its path,

In case of a force varying as the direct first power of the displacement, the corresponding equation is

$$y = x, \tag{7}$$

which is the equation of a line tangent to (6) at the origin, and hence, as before seen, for vibrations of small amplitude the two laws are approximately identical.

Now let a third law be assumed to be represented by an equation of a form such as

$$y = \tan x. \tag{8}$$

Since (7) is also tangent to (8) at the origin, for vibrations of small amplitude, the laws of force expressed by (7) and (8) will cause vibrations in which the distribution of kinetic and potential energy is approximately the same. If, however, sufficient energy is imparted to the vibrating particle so that the amplitude is not small, it is not difficult to see that the mean kinetic energy no longer remains equal to the mean potential energy, as it is when the law of force is expressed by (7), nor is the mean kinetic energy the less of the two, as when the law is expressed by (6), but instead it is now the greater of the two. This appears perhaps most clearly from the consideration that this case more nearly resembles, than do the preceding, that of an elastic particle rebounding between two fixed walls, in which case the mean potential energy vanishes and the mean kinetic energy is the total energy. Hence, it appears that when (8) is the law of force, the ratio of the mean kinetic energy to the total energy is greater than one-half, and increases with the amplitude of the vibration. This is true not only for the law of force expressed by (8), but for any law which is represented by a curve passing through the origin, tangent to (7) and falling on the same side of (7) as (8) falls.

From similar considerations it appears that whenever the curve expressing the law of force passes through the origin and is tangent at that point to (7) and falls on the same side of (7) as does (6), the mean kinetic energy of vibration will be less than half the total energy. Since in (8) the force of restitution becomes infinite at both $+\frac{1}{2}\pi$ and $-\frac{1}{2}\pi$, the oscillation is confined within those limits.

Let us now further suppose a law of force which will give a curve not having a point of inflection at the origin as does (6) or (8), but nevertheless tangent to (7) at that point.

Such a law is given by the equation

$$y = e^{-\tan x} \sin x, \tag{9}$$

if we take only that part of it lying between $x = +\frac{1}{2}\pi$ and $x = -\frac{1}{2}\pi$.

On the negative side of the origin the curve somewhat resembles (8), while on the positive side, after reaching a maximum value of y at a point a little beyond $x = \frac{1}{8}\pi$, the curve rapidly approaches the axis of x, and the force vanishes at $x = \frac{1}{2}\pi$. This is in effect a combination of the two previous cases, and corresponds evidently to the case of the molecules of a solid or fluid held at mean distances from each other which are fixed at a given temperature.

During one part of the vibration the mean kinetic energy is more than half the total energy, as has been just now shown, while during the other half the mean kinetic energy is less than half that amount. It will depend upon the precise relation between the two parts of the curve what the effect is on the whole. But it is perfectly evident that for large amplitudes the whole effect will be of the same character as if both parts were of the kind expressed by (6), and the mean kinetic energy is then less than half the total. But it is to be noticed that for certain amplitudes, which are not too large, the contrary effect is quite possible and the mean kinetic energy will be less than half the total energy. This is the kinetic explanation of the fact first established by Rowland,* that the specific heat of water slightly decreases as the temperature rises, from 0° C to about 30° C. A similar phenomenon has been observed in case of mercury.

But the most important conclusion which flows from the fact that the mean kinetic energy decreases with the amplitude is, that in this kind of vibration, also, there is a maximum value of the mean kinetic energy which can not be increased by increasing the displacement, unless the molecules be carried beyond the range of their mutual attractions. This is what occurs in vaporization with the resulting change of volume, and a large increase of the potential energy without increase of the mean kinetic energy.

As was shown in connection with the discussion of the oscillation of the pendulum, the character of the oscillation is unchanged when the value of x in (6) lies between $+\pi$ and $-\pi$, but entirely changes its character and becomes revolution if those limits are exceeded.

When the law of force is expressed by (7), the character of the vibration is unchanged, however great the amplitude of the displacement; and, similarly, in case the law of force is that expressed by (8), the

*On the Mechanical Equivalent of Heat, with Subsidiary Researches on the Variation of the Mercurial from the Air Thermometer, and on the Variation of the Specific Heat of Water. *Proc. Am. Acad. Arts and Sciences*, 1880.

general character of the vibration can not be changed however large the total energy imparted to the vibrating particle, and in this case the amplitude of the vibration evidently can not, under any circumstances, be increased beyond $\frac{1}{2}\pi$, but x must always lie between $+\frac{1}{2}\pi$ and $-\frac{1}{2}\pi$, so that as the amplitude approaches these limits the motion resembles more and more that of an elastic particle rebounding between a pair of immovable parallel walls at a distance π from each other.

When, however, the law of force is that expressed by (9), the amplitude of the vibration can not exceed $-\frac{1}{2}\pi$ in one direction under any circumstances, but in the other direction the amplitude can not exceed $+\frac{1}{2}\pi$ without a change from vibration to free motion.

The phenomena to be represented show that the same general relation holds for any law of force of which the curve has the general characteristics of (9), such as, for example, that part at the right of the origin of the curve

$$y = ax^{-2} - bx^{-5} \tag{10}$$

in which y is the force and x the distance between the molecules.

Such a curve as (10) must represent the facts of nature more accurately than the relation between them proposed by Maxwell, and expressed by the equation

$$y = -bx^{-5} \tag{11}$$

which was taken by him to express the force acting during an encounter. But the law of force during an encounter can not be supposed to differ from that existing during any state of nearness of the molecules, so that (11) is to be regarded merely as an approximate expression for a law like that of (9) or (10), in which the part of the ordinate of the curve expressing the attraction of the molecules is neglected. It must be noticed that the origin in (10) and (11) is differently situated from that in (9), as will be seen upon sketching the curve. The line $x = -\frac{1}{2}\pi$ in (9) is that taken as the axis of y in (10) and (11),

Having now considered in general the nature of the change which occurs in the molecular motion during vaporization, a somewhat closer consideration will enable us to see the remarkable mechanical significance of the so-called critical temperature, as well as that of ebullition. In ordinary evaporation into the atmosphere, without ebullition, only those molecules escape from the surface, whose kinetic energy is such as to enable them to overcome cohesion, and only so many can escape as will enable the vapor to fulfill approximately the law of Gay Lussac. The process by which the vapor tension in this case acquires its maximum value, is one whose velocity is regulated by the laws of gaseous diffusion,

when the vapor tension is less than the atmospheric pressure. But when the temperature rises to such a degree that the mean kinetic energy of the molecules (which, according to our theory, may be the same in both liquid and vapor) is greater than that of the superincumbent atmosphere, the vapor no longer merely diffuses from the surface, but is able mechanically to push back the atmosphere, or other pressure, to which it is subjected, and ebullition takes place. Even in the case of ebullition, however, only part of the molecules are able to free themselves from the force of cohesion, namely, those molecules which happen to have a kinetic energy so far above the mean as to carry them out of the range of the force of cohesion, and enable them to push back the superincumbent pressure. If, however, the temperature be still further increased, a point must at last be reached, whatever be the volume and consequent pressure, such that the mean kinetic energy is greater than the maximum possible in the liquid state. The liquid must then become a gas without regard to volume or pressure. The temperature at which this occurs is the critical temperature for the liquid considered.

There are then three kinds of vaporization possible, evaporation, ebullition, and gasification.

There appears, however, to be only one kind of liquefaction (melting) which is most nearly analogous to gasification, and without further reasoning it will appear that for those substances whose melting point is lowered by pressure, there must be a critical temperature of melting above which the body will be liquid, whatever be the pressure, *i. e.* no pressure can lower the melting point beyond a certain amount dependent upon the constitution of the body.

The results of these views as to the mechanics of liquefaction and vaporization are in general accordance with the hypothesis of Clausius,* who supposes that the mean kinetic energy or "real specific heat" does not depend upon the state of aggregation of the body, and they are in exact accordance in this particular that the mean kinetic energy need not be changed by change of state from solid to liquid or from liquid to gas. But whether the translatory motion of the molecules is the direct physical cause of radiant heat is still an open question which we shall discuss more at length in another place, where we shall also take occasion to discuss the relation between the specific heats of a body in its different states of aggregation, solid, liquid, and gaseous.

There is, however, one point which may perhaps be well considered

*Phil. Mag. [4] **24**, 204 (1862).

in this connection, and that is the explanation of the very large specific heat of liquids, compared with the same substances in the solid or gaseous state. This appears to be very probably due to the effects of the centrifugal force developed in the freely rotating molecules. The law of most probable distribution of rotary velocities shows that although the larger number of molecules are rotating with a velocity whose square is near the mean, yet all other velocities also exist, and among them very great ones.

Those rotary velocities which are sufficiently great will dissociate the atoms of the rotating molecules from each other, and the energy of rotation being expended against atomic forces will become potential and will not again become an available part of the kinetic energy until the atoms so separated meet others with which they can reassociate into molecules. A certain small per cent. of the total mass of the liquid must continually be thus dissociated in order that atoms may meet sufficiently frequently so that reassociation may be possible, and a uniform condition exist, in which as much reassociation happens as dissociation. This quantity must increase with the temperature, and the energy thus employed is apparently the reason of the high specific heat of liquids. In electrolysis these dissociated molecules are mechanically separated from the others, and to keep up the per cent. of dissociation a new supply is required for which energy must be supplied, just as it must be to preserve the temperature of a fluid from whose surface vapor is constantly being removed. A somewhat analogous phenomenon occurs in vaporization, but as it can occur ordinarily only at the surface, the analogy has been overlooked. A liquid gives off vapor at temperatures below boiling. According to the theory broached in this paper, only those molecules pass beyond the range of the cohesive forces whose kinetic energy is sufficiently above the mean to enable them to overcome the cohesive force and have still remaining on the average an amount of kinetic energy equal to the mean.

But this can occur only at the surface, for inside the mass of the fluid such molecules are entangled and soon lose this superfluous energy in encounters with other molecules. We may, perhaps, put the comparison in a clearer light by supposing a liquid, in which no such dissociation occurs, such as mercury probably is, and let it be in connection with a large closed space which is filled with the vapor of the liquid at its maximum tension. Now raise the temperature of the fluid and wait until the vapor in the closed space has reached the tension corresponding to this temperature. The heat supplied is partly employed in increasing the kinetic

energy, and partly in vaporizing a portion of the liquid, and is much larger in amount than would be required if there was no vaporization. In a quite analogous manner, the heat energy necessary to raise the temperature of water would probably be much less were there no dissociation accompanying the increase of temperature.

It appears from experiment that the specific heat of mercury is nearly the same in its solid and liquid states as it should be in case its molecules are monatomic in both states. It would be of great interest to know whether the specific heat of mercury gas has also the same value. It is noticeable that the latent heat of liquefaction of mercury is extremely small, which would lead to the hypothesis that the atoms of mercury are very nearly round and smooth, and that the rotary energy of a molecule of mercury is but a very small fraction of its total kinetic energy.

Cadmium, which is monatomic as a gas, would also furnish an interesting test of the theory, for it is not likely that the molecule of a substance greatly changes its character by change of state. Dissociation of the atoms of a molecule is evidently due to the motion of atoms away from each other. It is yet a question as to whether such oscillations can be caused in the atoms of a molecule as to absorb an appreciable amount of energy, or of such intensity that they can be caused to rotate. If such rotations are ever caused within the molecule itself, they probably occur at temperatures far above vaporization.

The conclusions to be drawn from the specific heats of elementary substances, whose molecules consist of but two like atoms, are in general confirmatory of the theory proposed in this paper, for the amount of rotary energy for such substances should be a less fraction of the total energy than in bodies consisting of a larger number of atoms, and the per cent. of dissociation should also be less. Now, in fact, for such bodies the specific heat in the liquid state does not, in general, greatly exceed that in the solid.

NOTES.

Influence of Time in Fertilizer Analyses.

BY ROBT. B. WARDER.

[The following note illustrates a practical application of the studies in dynamical chemistry undertaken by the Section of Chemistry and Physics. See page 51.]

Mr. H. A. Huston has examined the "influence of time and temperature on the amount of phosphoric acid dissolved from commercial fertil-

izers by citrate of ammonium."* From a sample of raw bone fertilizer containing 20·28 per cent. P_2O_5, ammonium citrate solution of 1·09 sp. gr. at 40° C. dissolved

In 30 minutes, 4·01 % P_2O_5
" 45 " 4·97 "
" 60 " 5·92 "

Each of these values is a mean of three gravimetric determinations.

The solution was evidently incomplete. The chemical operations involved are somewhat obscure. Since a very large excess of citrate was present (about 40 mol. citrate to one of phosphate), we may apply the hypothesis that the rate of solution at each moment is proportional to the phosphoric acid still present that is capable of being so dissolved, or

$$\frac{-du}{dt} = au, \dagger \text{ and}$$

$$\log \frac{u_0}{u} = At.$$

According to this hypothesis, the most probable value for the limit of solubility, under the conditions of the experiment, is 7·8 per cent. of the raw phosphate, or 38 per cent. of the total phosphoric acid. For the calculated values below, A = 0·0107.

	Percentage of P_2O_5 dissolved.		
Time.	Observed.	Calculated.	Difference.
30 minutes	4·01 (mean)	3·91	·10
45 "	4·97 "	5·05	·08
60 "	5·92 "	5·86	·06

The differences in this table are far less than those which appear in the several determinations upon which the means are based; yet this apparent agreement is no real proof of the hypothesis proposed or of the limit deduced, for which further experiments would be required. Mr. Huston very aptly emphasizes the importance of a uniform scale of time and temperature for determinations of reverted phosphoric acid. Some chemists are inclined to discard the citrate method entirely, as unreliable. The term "reverted phosphoric acid" is very objectionable, since it implies a previous solubility; but some test for relative present solubility is demanded by dealer and consumer. Far more concordant results can be expected if the reagent used is allowed to act until the limit is nearly reached, than if the time and temperature adopted allow but fifty or seventy-five per cent. of the soluble matter to be taken up. It will be seen, for example, from Mr. Huston's figures, that an error of a single minute in the time of action at 40° would result in an error of more than 0·06 per cent. "reverted phosphoric acid." The "Washington method"‡

*Indiana Agricultural Report for 1882, pp. 230–233.

†This equation is explained and discussed in the paper on "Urech's Investigation of the Speed of Inversion of Cane Sugar," these PROCEEDINGS, **1**, 167–178 (Dec. 1882).

‡Proceedings of Convention of Agricultural Chemists held at Washington, D. C., July 28, 1880.

requires an exposure of the fertilizer to a solution of ammonium citrate at the ordinary temperature for an indefinite time (during elutriation, grinding, etc.) after which the "flask is put into a cold water-bath, the temperature is rapidly raised to 40° C., and there maintained for one-half hour." Under such conditions, great variations in the analytical results are inevitable. A summer temperature of 30° C. (according to Mr. Huston's results) effects solution about two-thirds as rapidly as at 40°; while the interval required to bring the temperature to 40° will vary greatly according to the size of the water bath and many other conditions. As a hint toward more accurate experiments in this direction, the hypothesis and figures stated above would indicate the solution of 7·6 per cent. of P_2O_5 in 9¾ hours, while 7·02 per cent. (or nine-tenths of the whole amount) would be dissolved in 2½ hours.

The desired uniformity of method for official analyses in the several States has not yet been secured;* a careful study of the dynamical phase of the problem may contribute to the selection of suitable conditions.

Purification of Drinking Water.

BY DR. F. ROEDER.

[Read before the Department of Science and Arts, May 10, 1883. Reported in *Science* I, 490 (June 1, 1883).]

From three to six drops of officinal dialysed iron, added to one liter of muddy water from the Ohio River, will precipitate the suspended solid matter. About two drops of the reagent are required to clarify water colored with one drop of blood. Albuminoids are removed by dialysed iron; perhaps, also, the other organic contamination. The precipitate, including all the iron, may be separated by filtration or decantation, leaving the water perfectly bright and transparent, and free from unpleasant taste or smell. For purification on a large scale, ferric chloride and sodium carbonate may be used in proper proportion. The small quantity of sodium chloride formed will not impair the taste of the water.

* The New Jersey law specifies a temperature under 38° C. (100 F.) for the solution of reverted phosphoric acid, with no limitation in regard to time. In a very interesting investigation conducted by the N. C. Agricultural Experiment Station, "the cold flasks were put into the bath warmed to 40° C., and left there forty minutes," in order to secure a "temperature of 40° C. in the contents of the flask for about thirty minutes." See Report for 1882, page 51. Results so obtained may be comparable among themselves, but are likely to differ from those of other observers.

Schedule of the Friday popular Scientific Lectures to be given by the Department of Science and Arts, during the season of 1883–4, at the Lecture Hall of the Institute, corner Sixth and Vine Streets, Cincinnati:

November 9. Professor T. C. MENDENHALL, Ohio State University.
Subject: The Electric Light.

December 14. Professor C. LEO MEES, Ohio University, Athens.
Subject: Molecular Motion and Crystallization.

January 11. Professor F. W. PUTNAM, Peabody Museum, Cambridge.
Subject: Ancient Arts of North American Nations.

January 25. Dr. ALFRED SPRINGER, Cincinnati.
Subject: The Cell and its Functions.

February 8. Professor E. S. MORSE, Salem, Mass.
Subject: Japan—its People and Industrial Occupations.

March 7 Professor THOS. FRENCH, JR., Cincinnati University.
Subject: Sound.

March 21. Professor W. L. DUDLEY, Cincinnati.
Subject: Water.

April 4. Professor T. H. NORTON, Cincinnati University.
Subject: Recent Advances in Chemical Technology.

April 18. Professor J. B. PORTER, Cincinnati University.
Subject: Mining and Metallurgy.